

# METALLURGIA

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## Photography of Metals\*

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*Photography is rightly regarded as an indispensable tool in industry and research, and although in other respects it enters into the life of almost everyone, its application to the investigation of metals is the more direct concern of the author of this article. The subject is discussed in three main sections; straight camera photography; photomicrography; low-power photomicrography, and macrophotography.*

**P**HOTOMICROGRAPHY is the photography of microscopic subjects, involving the use of a camera in conjunction with a microscope. It is often confused with microphotography, which is the production of microscopically small photographs. The following notes explain the principles involved in photomicrography, and describe the type of apparatus needed.

**Apparatus.**—A photomicrographic outfit consists essentially of a microscope, an illuminating system, and a camera. Dealing with the microscope the first point to be appreciated is the difference between pathological and metallurgical microscopes. The pathological microscope consists of a stand with a tube which racks up and down and carries at the lower end the objective, or the lens of the microscope, and at the upper end the eyepiece or magnifying ocular, which magnifies the image produced by the objective. Below the tube is a fixed stage which carries the specimen. Below the fixed stage is a sub-stage carrying a condenser capable of being racked up and down. At the end of this rack is fixed a reflecting mirror in a gimbal. The illuminating system provides a beam which is reflected by the mirror into the sub-stage condenser and through the specimen. Pathological specimens are usually so thin that the light can be transmitted through them into the objective.

The metallurgical microscope is similar in many respects but has certain important differences. For example, the stand of the instrument is of heavier construction, for it often has to carry heavy specimens, and this applies especially to the stage, which is frequently made to rack

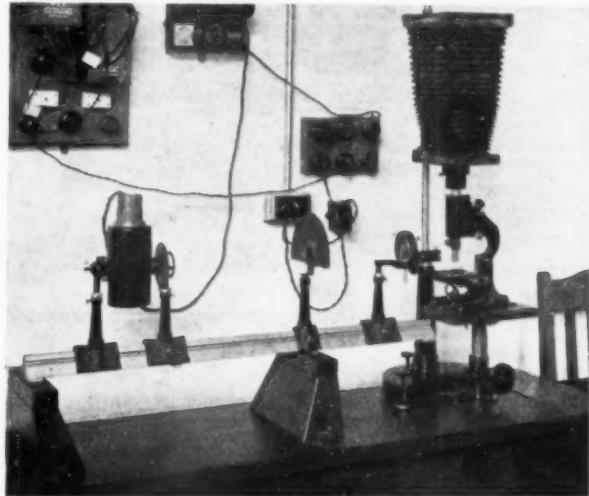


Fig. 10.—Photomicrographic outfit showing microscope in position with camera above it.

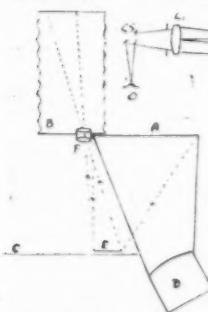


Fig. 9.—Diagram of illuminating system for photomicrography.



Fig. 12.—Diagram of illuminating system and camera set up for macrophotography.

up and down. The tube, objective, and eyepiece are all similar, but the sub-stage condenser and mirror are absent. The reason for this is that with metal sections it is not always possible or desirable to obtain specimens thin enough to transmit light, and so the photomicrographer has to depend on the light which can be reflected from the surface of the specimen.

Two methods of illumination are used, according to the effect desired. Light may be supplied from the sides, at an

angle to the axis of the tube, in which case light from the smooth parts of the specimen will be reflected away from the objective, producing the effect of light patches on a dark ground. This method, known as oblique illumination, is not often used alone, but usually in conjunction with the second method—namely, vertical illumination. In this method light is supplied to the specimen on the axis vertical to the surface and reflected back along the same axis. Because of the position of the microscope tube above the specimen, a reflector must be introduced along the vertical axis of the microscope tube. The working distance between the objective and the specimen for magnifications of  $\times 25$  and over is so small that the reflector cannot be placed between the objective and the specimen, but must be inserted between the objective and the microscope tube. A beam of light from the illuminating system strikes the reflector and is diverted through the objective, which in this case acts as a condenser, and is reflected from the specimen back into the objective, which now functions as such; and thence to the eyepiece. It is clear that the reflector could not be a circular silvered mirror, for then either no light would reach the eyepiece, or the mirror would act as a central stop. Even a semi-circular mirror would interfere with the aperture of the objective. A prism might be used, but this again would interfere with the objective aperture. The most satisfactory reflector is a glass slip suitably inclined to the axis; its main drawback of producing glare can be overcome by rigid control of the illuminating beam, as described below.

\* Continued from page 97, February issue.



Fig. 11.—Close-up of microscope, showing ring illuminator in position.

To obtain the greatest resolution, together with size of field, and definition, the full working aperture of the objective must be utilised. This can be determined by reflecting on to the back lens of the objective a conical beam of light which is controlled so as to just fill the aperture, and which may be varied to suit different objectives. The glare from the objective and from the glass slip of the vertical illuminator is reduced to a minimum by adjusting the beam so that only the field required is illuminated, and all extraneous light removed. This condition is called "critical illumination," and is obtained as follows:—

The source of illumination is a point-o-lite P (see Fig. 9) in front of which is a lens L having a focal length short

Fig. 15.—Photomicrograph of tin containing 0.006% copper annealed at 220° C. for one month, showing traces of Cu-Sn in the grain boundary.  $\times 2,500$ .



Fig. 16.—Photomicrograph of electro-deposited bronze containing 17% tin.  $\times 1,500$ .

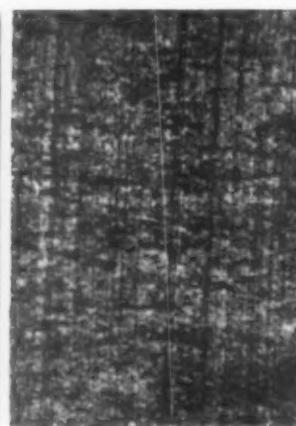


Fig. 13.—Photomicrograph of pure tin as cast.  $\times 100$ .



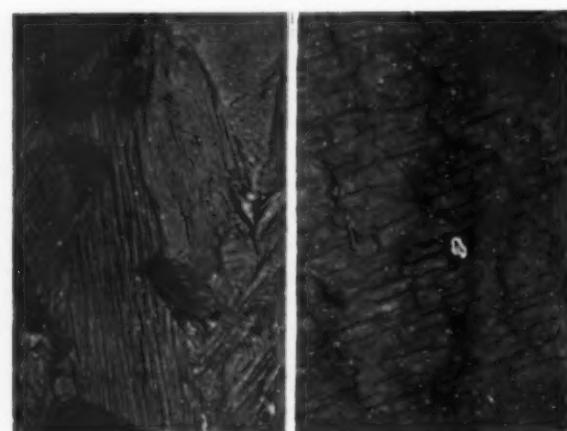
Fig. 14.—Photomicrograph of pure tin as cast, showing traces of bismuth.  $\times 100$ .

enough for the lens to be quite close to the bulb of P and to produce a sharp image of the point-o-lite on the lens  $L^1$  at about 20 in. from L. The lens L has a high aplanatic correction. The lens  $L^1$  is of 5½ in. focal length, and focuses a sharp image of the lens L on the back lens of the objective O. By means of an iris diaphragm of  $L^1$  it is possible to control the size of the cone of light falling on O, so that it just fills it with light. The objective O focuses a sharp image of  $L^1$  on the surface of the specimen, and by means of the iris diaphragm of  $L^1$  it is possible to control the size of the field illuminated. The diagram shows the beam turned through 90° by the glass slip reflector GS.

The apparatus itself is simple in form (see Fig. 10). It consists of a table 5 ft. long on which a metre V-bar is fixed, raised about 8 in. above table level. This V-bar carries the point-o-lite P and the lenses L and  $L^1$  on saddles. At the end of the V-bar, where  $L^1$  is situated, a hollow metal block is fixed on the table, on which the microscope stands. On the table, and sliding up and down a single rod fixed to a heavy base, is the camera, which can be dropped down on to the microscope, or raised and swung out of the way. The camera has an extension of about 45 cms.

By using light of a shorter wave-length better resolution is obtained. This is done by replacing the point-o-lite with an Osira mercury vapour lamp. The outer pearl glass globe is removed and the quartz tube filled with mercury vapour is now used as the source of illumination, and a yellow screen No. 2A Wratten is used to prevent harmful radiation reaching the eye. Care has to be taken that the tube length of the objective is now corrected for blue light,

Fig. 18.—Tin-base bearing metal containing 7% antimony, 3.5% copper, showing precipitation of Sb-Sn.  $\times 2,000$ .



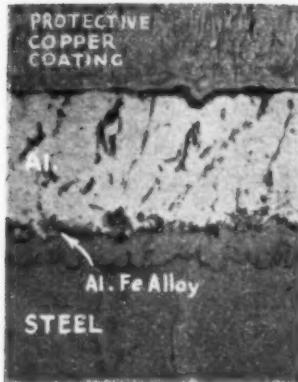


Fig. 19.—Composite photomicrograph of hot-dipped aluminium coating on steel.  $\times 500$ .

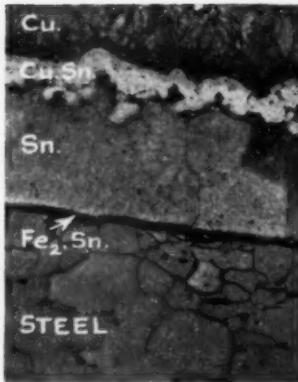


Fig. 20.—Electro-deposited tin on steel with a protective electro-deposited copper coating on the tin and the whole specimen annealed at 200° C. for 24 hours, showing Fe<sub>2</sub>.Sn and CuSn layers.  $\times 500$ .

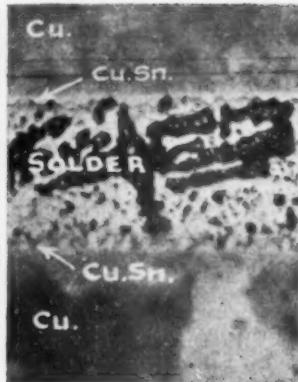


Fig. 21.—Eutectic lead-tin soldered copper joint.  $\times 500$ .



Courtesy of Electrodepositors' Technical Society.  
Fig. 22.—Electro-deposited tin on steel seamed and cross-sectioned through seam, showing break-up of coating.  $\times 500$ .

and a suitable blue filter is used, and the image focused in the blue. This is difficult at first, as the visual image lacks contrast, but the worker after practice becomes used to the image and is able to focus it accurately. Figs. 13 to 22 illustrate the work which can be carried out with the apparatus described.

Should it be necessary, oblique illumination may be used in place of vertical illumination. In this case a ring illuminator (see Fig. 11) is used for powers up to  $\times 250$ . This ring illuminator is fitted to the upright of the camera stand by means of a clamp, and consists of a ring of 12 lamps of the 8-volt type, set at an angle of about 45° to the horizontal, enabling the specimen to be illuminated obliquely from every side. The lamps are so arranged that each one can be taken out of the circuit and the specimen illuminated from any of several directions.

*Preparation.*—The examination of metal sections under the microscope cannot be attempted unless the metal surfaces have been properly prepared. The usual method of preparing specimens for photomicrography is as follows:

The surface to be examined, if not sufficiently flat, is rubbed on a second-cut file, the file being held in the hand and the specimen rubbed on it. This ensures the surface being rubbed flat. The specimen is so rubbed that all the file marks are in the same direction. When the specimen is level, and all surface marks have been removed, the specimen is then rubbed on emery paper (Oakey's No. 0), so that the emery scratches are at right angles to the file marks. When all the file marks have been removed, the process is repeated for successively finer grades of emery paper, in each case turning the specimen through 90°, so that it can be observed when the scratches of the previous paper have been removed. The recommended fine emery papers before the war were Hubert's 1M, 1F, 0, 00. As these are now unobtainable, equivalent grades of other makes can be used. If well-worn papers are used the 0 paper can be dispensed with. Depending on the metal to be polished, benzine and B.P. paraffin are used as lubricants on the papers. It may be that the metal section cannot always be rubbed down on the file immediately, but has to be cut from a larger section. In this case care has to be taken that the cut does not disturb the structure of the specimen too much. The care required varies with the metal. The selection of the portion to be cut and examined is the job of the metallurgist, but in any case it will be as well, if possible, to cut a piece  $\frac{1}{2}$  in. to  $\frac{3}{4}$  in. cube, this being the most convenient size to prepare for photomicrography.

On the other hand, a specimen may be too thin or too small to be prepared satisfactorily, and has to be mounted. There are a number of mountants, including bakelite sealing wax, "Wood's metal," sulphur, mechanical clamp,

etc. The specimen is mounted in one of these, and then carefully sectioned, so that the specimen is not disturbed in the mountant. After the specimen has been rubbed on the papers it is then ready for polishing.

There are many methods of polishing metal sections, but they roughly divide into (1) hand polishing, (2) rotating-block polishing, (3) electrolytic polishing, the last being the most recent. In the case of the first two, the underlying principle is a soft basic material, such as velveteen, chamois leather, and, more recently, pure lead, impregnated with a cutting material as metallic oxides, chalk, etc., and lubricated with water, benzine, paraffin, etc. The soft material is stretched out, either on a block of hard wood in the first case, or in the second on the block of the machine. The soft material is then impregnated with the cutting powder and lubricated. When hand-polishing is employed the specimen is rubbed on the pad with a circular motion until all the emery scratches are removed. When using rotating-block polishing a circular metal block carrying the pad is rotated, and the specimen held on to it and slowly rotated against the direction of the polishing pad. Most methods, however, are a combination of these two, usually a machine polish first to remove the emery scratches, and then a final polish by hand. Harder materials, such as steel, bronze, etc., usually only need the machine polish, whereas softer materials, such as tin, lead, etc., can be polished by hand alone, using first a quick-cutting material such as a metal polish and finishing off with a slower-cutting material, such as aluminium oxide. After the first polishing the specimen is usually given a preliminary dip in an etching reagent, to remove the flowed or disturbed layer produced by the mechanical working of the surface in the rubbing down. In the case of harder metals this

Fig. 23.—Macrograph of small ingot section of tin as cast, containing 0.75% copper. Oblique illumination.  $\times 21$ .

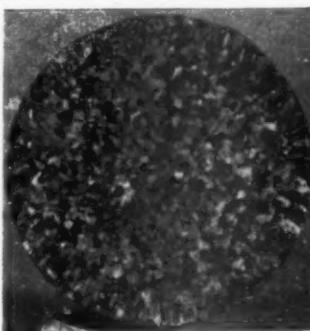


Fig. 24.—Macrograph of a piece of etched tinplate. Oblique illumination.  $\times 1$ .



may not be necessary, but if so is limited to once or twice. In the case of softer metals, several etchings are necessary, pure tin needing as many as 20 to 30. When the specimen has received its final polish, it is well washed, then rinsed in acetone, and, if a hard metal, may be dried on a soft cloth, but if a soft metal, it is dried in a warm air blast.

The specimen is then examined for holes, gaps, non-metallic inclusions, such as sulphides, etc., and, if necessary, photographed; otherwise it is etched. This etching is not so drastic as the preliminary one, and should be more differential. When the specimen is etched it is then ready for full examination and photographing.

**Photography.**—The photographic technique has no unusual features, but the type of plates needed should be mentioned. In the case of point-o-lite illumination, a blue-green screen of the Chance-Watson type is used, and it is found effective for most metallurgical subjects with the exception of copper and bronze, when an orange screen is used. In both cases a plate of the screened type is used together with an M.Q. developer. When blue light is used a filter of the tricolour projection type is best, and it is found that a blue sensitive plate is required. The undyed press type of plate meets this requirement and can be obtained as a special plate from Ilford, Ltd. In this case the developer used is M.Q., of the type recommended for the soft gradation panchromatic plate, the resulting negative being rather soft.

#### Low Power Photomicrography and Macrophotography

Macrophotography is the photography of metal structures which can be seen with the eye. It would seem that macrophotography is the link between photography and photomicrography, for some macrostructures need no magnification to show them clearly, whereas others are more clearly portrayed if slightly magnified. It is, of course, sometimes necessary to relate the macrostructure to the microstructure, and so a greater degree of magnification becomes necessary.

#### Micro-Copying of Documents

INSURANCE of valuable plant is standard practice in every industry, but it is not usual to insure documents or records because money cannot replace them. Nevertheless, for an amount less than the insurance premium these records can be photographed in such a way that they can be inspected at any time or reconstituted in their original form if the master records should unfortunately be damaged. To meet the needs of copying many thousands of records the technique of micro-copying has been developed, whereby continuous lengths of small negatives are obtained on special cinematograph film. According to the apparatus in use, from 800 to 4,000 negatives can be obtained on a 100-ft. length of film which fits into a tin only 4 in. in diameter. Hence many thousands of these records can be stored in a safe and occupy only a small fraction of the space required by the originals.

Evidently micro-copying can be recommended to every firm, first as a part of necessary air-raid precautions, but more particularly as an adjunct or corollary to the insurance policies taken out for the protection of the company's assets. It can thus be seen that it concerns every departmental manager, who should make representation to the secretary about the safeguarding of the particular records under his control.

There is no mystery about micro-copying. You can do it yourself or have it done for you. The special photographic films for this work are manufactured by Ilford, Ltd., and the whole process is described in detail in a booklet, "The Technique of Micro-Copying," issued free by this company. Alternatively, they have a special document copying department equipped to undertake this work in the most economical manner.

Assuming that it has been decided to adopt micro-copying, it is necessary to obtain a suitable special camera, but owing to the large amount of micro-copying being

**Apparatus.**—From the foregoing, it is obvious that with certain modifications the apparatus already described under the headings "photography" and also "photomicrography" can also be used for this work.

The only modification necessary to the photographic apparatus is the use of a shorter focal length lens and a conical adaptor made to screw into the 8-in. lens flange at one end, and take the short focal length lenses at the other and narrow end. This adaptor should be about 6 in. long, thus adding this amount to the bellows extension.

It is in macrophotography that oblique illumination is used more widely and in conjunction with vertical or approximately vertical illumination. Approximate vertical illumination has been described under "Photography," but it may be as well to explain it diagrammatically (see Fig. 12). A white card A is pinned to the front of the camera B, and the specimen E is fixed to the easel C (or placed on the moveable shelf). The lens F is swung as far as possible to the same side as the white card A. A is evenly illuminated by a focuslite spotlite D. The specimen will reflect that which is in front of it—namely, the white card. The result is that the specimen appears light and any irregularities or spots on the specimen will scatter the light and appear dark.

This method can be used for magnifications up to  $\times 10$  by the use of the short focus lenses. Beyond this and up to magnifications  $\times 25$ , a modified form of the photomicrographic apparatus is used. Figs. 23 to 25 are examples of work carried out as described.

For facilities in preparing this paper, and for permission to reproduce the photographs made in the Tin Research Institute, the author is indebted to the International Tin Research and Development Council.

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2. "Tinning of Steel Strip by Electrodeposition," Part II, D. J. Maenoughton and J. C. Prytherch, *Journal of the Electrodepositors' Technical Society*, 1937, **12**, 45-80. Tin Research Institute Publication A 52.
- Fig. 4 reproduced from Tin Research Institute Publication B 4.
- Fig. 22 reproduced from Tin Research Institute Publication A 52.

done and the difficulties in manufacture of special apparatus to-day, it may be difficult to purchase just what is required at a reasonable price, but we are informed that it is comparatively easy to purchase second-hand 35 mm. cinematograph cameras of an out-of-date type for £20 to £30 which are admirably suited for the micro-copying of documents, and only require slight alteration and the provision of a suitable stand. When purchasing film from Ilford, Ltd., all the necessary advice can be obtained and the exposed film is best sent to the manufacturers for processing. If the work is carried out in a satisfactory manner, any one or all the negatives can be enlarged back to their original size whenever this should prove necessary. Of, if the records are required at another factory or in another country, duplicates of the micro-films can be made quite simply and considerably more cheaply than by rephotographing them.

Apart from the copying of records, micro-copying has a number of other important uses, such as important original drawings and designs, and the collection and collation of scientific papers in the research department. A micro-copy of an important reference is of far greater value than an abstract and avoids continuous journeys to the big central libraries. When it is required to consult these micro-copies they can be projected on to a screen by any miniature projector and read at leisure.

Secretaries of companies will have had their attention drawn to the new Order S.R. and O., 1941, No. 1778, by which it is now permissible to dispose of share transfer certificates, by which means the Government hopes to liberate large stocks of paper for re-pulping. But if it is felt that there is any possible risk involved in destroying these records, it is an easy matter to have them micro-copied, and there is the further advantage that an enormous amount of storage space becomes available for some more useful purpose.

# METALLURGIA

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## Post-War Trade and Industry

**W**E are living in very critical times and the need for directing all the energy at our command towards the successful prosecution of the war is so vital that there is a tendency to overlook the fact that just ten years ago the Import Duties Act received the royal assent. It is not proposed to attempt to review the effect on trade and industry of Britain deliberately becoming a protectionist country, because since the war import duties have had little or no influence on the course of trade : some of them have either been reduced or entirely abolished. In any case, it would certainly be very difficult or impossible to disentangle the results of protection from those of general recovery of world conditions ; it is, however, perhaps true to say that the direct effects of the Act have been less than were expected at the time. It is, of course, noteworthy that under protection the home trade recovered fairly rapidly, whereas the export trade remained for several years a drag on recovery.

The effect of import duties on industry is, of course, reflected largely by trade, but their effect on the iron and steel industry in particular appears to have been in the national interest. At that time this industry was in a very low state, and considerable efforts had been made to re-establish it on a firmer competitive basis, but lack of confidence, associated with a world-wide depression, undoubtedly retarded development. The manufacturers appreciated the need for greater efficiency in their works, but with low outputs and no security in the home market, it was, in many cases, impossible to embark upon extensive schemes of reorganisation. Many believed that once a proper system of tariffs was imposed there would be marked development in carrying out necessary improvements ; others, on the other hand, were unable to express an opinion because the forces working outside those exercised by tariffs were considered so numerous and complex that it would be hazardous. It must now be admitted that the industry itself has been more prosperous than it was before tariffs were imposed, and some part of this revival is undoubtedly due to the influence of import duties. By enabling it to consolidate its position in the home market, the industry has organised its production on a more economic basis, and up till the outbreak of war had been able to improve its competitive position in the world's markets, and through Imperial and international co-operation it became more prosperous. The imposition of import duties gave an impetus to long-range schemes of reorganisation throughout the whole industry and to the installation of new plant and equipment. In the present critical position of the country, however, the most important effect of the tariffs on this industry is the assistance they have undoubtedly given in making it prosperous and more efficient, because it must now be realised that the maintenance of a prosperous iron and steel industry in the highest degree of efficiency, while essential to the economic progress of this country, is vital from the point of view of national security.

What the future holds in store for dealing with world trade is unfathomable, but that it will ever return to uncontrolled conditions cannot be seriously advocated.

Two possible lines of development have been suggested : either the State in order to secure the public interest will have to interfere more and more deeply in the conduct of ordinary business, or protection in Great Britain, as in the United States, will have to be accompanied by anti-trust legislation to enforce competition and prevent restriction. An interesting contribution on the subject has been made by Mr. Raymond Streat, chairman of the Cotton Board, who suggests a system of trade agreements which will definitely and effectively expand international trade, but at the same time moderate the suddenness and violence of the changes which are just as inevitably associated with expansion as with contraction. Vital raw materials are to be outside the scope of these agreements, and are to be the subject of international supervision designed to assure their equitable distribution and prevent their use for war. He makes the novel suggestion that each country will have the right to schedule for special treatment three or four staple export lines which will be commodities constituting an important part of the export trade of the scheduling country.

The significance of the agreement between the United States and British governments, recently signed by Mr. Sumner Welles and Lord Halifax, may easily be overlooked in the stress of circumstances. The terms of this agreement are sensible and satisfactory. The United States reaffirms its determination to continue to supply aid to Britain, and Britain undertakes to supply the United States with such reciprocal aid as she is in a position to give. The final determination of the conditions upon which Britain receives lend-lease aid and the benefits to be received by the United States is deferred to a later date. It is noteworthy that any "defence articles" transferred under the Act, which, at the end of the war, have not been destroyed, lost, or consumed shall be returned to the United States. Nothing could be fairer than that, and it will certainly come as a relief to some manufacturers who suffered grievously after the last war from a market flooded with surplus war materials and machines. With the possible exception of the shipping industry, there are very few industries likely to take exception to this clause.

But this agreement will undoubtedly have great effect on post-war trade and industry. It is important to observe that in the final determination of the benefit to be provided to the United States in return for lend-lease aid the conditions shall be such as not to burden commerce between the two countries, but to promote mutually advantageous economic relations between them and the betterment of world-wide economic relations. To that end it is intended to include provisions for agreed action by the two countries for the participation by all other countries of like mind directed to the expansion by the appropriate international and domestic methods of production employment and the exchange and consumption of goods, which are the material foundations of the liberty and welfare of all peoples. To the elimination of all forms of discriminatory treatment in international commerce and to the reduction of tariffs and other trade barriers, and, in general, to the attainment of all the economic objectives set forth in the Atlantic Charter. The best means of attaining these objectives will be discussed at an early date.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

At present it is too early in this struggle to foresee or define the precise detailed terms, but the agreement lays down certain broad principles for a settlement which will be open to participation by all other nations of like mind.

A successful agreement between Britain and the United States—both in word and in deed—would mean the subjugation of purely selfish interests to the general well-being of the two nations. Such a result would have a valuable moral effect on the peoples of all nations and would indicate possibilities for its wider application. The interdependence of all trade is both national and international, and agreement on the lend-lease aid problems

will pave the way to a solution of wider world problems, but this will only be possible if the problems are faced in a spirit of co-operation. When this war ceases large parts of the world will be destitute and its peoples demoralised: there will be a state of chaos and a tremendous effort will be necessary to restore some degree of order. No one nation will be in a position to achieve this task: it is a task for all nations that are capable of subjugating conflicting interests to the common good and are willing to remove or minimise restraints to world trade. Britain and the United States, by this agreement, will promote confidence and stability of which the world will be so much in need.

## The Institute of Metals

**T**HE thirty-fourth annual general meeting of the above Institute took place at the offices of the Institute, Grosvenor Gardens, London, S.W. 1, on March 11, 1942, the President, Lieut.-Col. the Hon. R. M. Preston, D.S.O., being in the chair. The minutes of the last general meeting were read and approved, and the Secretary read an abstract of the Report of Council for the year 1941, which was adopted on the motion of the President.

In the report it was stated: "The Council presents its thirty-fourth annual report with a sense of relief that the year has ended much more satisfactorily for the Institute than seemed possible a year ago. In spite of the intensification of the war, its publications have continued to appear regularly (if in somewhat diminished volume, for the reason that certain papers cannot at present be made public): and its financial position has been strengthened so that when, with the coming of peace, the floodgates of metallurgical information are opened, there should be available sufficient funds to allow of the publication of this matter without involving the Institute in financial embarrassment. For this satisfactory state of affairs the Council is indebted to the firms who have so generously contributed to the Endowment Fund and to the War Emergency Fund."

The following officers were elected for the year 1942-43:—President: Lieut.-Col. Sir John Greenly, K.C.M.G., C.B.E., M.A. Vice-Presidents: Horace W. Clarke and H. S. Tasker, B.A. Members of Council: G. Wesley Austin, O.B.E., M.Sc.; W. F. Brazenor; and H. W. G. Hignett, B.Sc.

The President presented the Platinum Medal for the year 1942 to Mr. W. Murray Morrison, Deputy Chairman and Managing Director of the British Aluminium Co., Ltd., with an appropriate speech in which he referred to Mr. Morrison's great services to the aluminium industry since its inception in this country, and the energy and foresight he displayed in harnessing the hydro-power resources of the Highlands of Scotland. Reference was made to the fact that Mr. Morrison is an original member and Fellow of the Institute of Metals, and has served on the Council for sixteen years. Mr. Morrison suitably responded.

### Technical Session

At the conclusion of the business of the meeting several technical papers were presented for discussion. These included "Surface Hardness of Metals," by Dr. Bruce Chalmers; "Constitution of Alloys of Aluminium with Magnesium and Silicon," by H. W. L. Phillips; "Constitution of Alloys of Aluminium with Magnesium and Iron," by H. W. L. Phillips, and "Constitution of the Aluminium-rich Alloys of the Aluminium-Nickel-Iron and Aluminium-Nickel-Silicon Systems," by H. W. L. Phillips.

In the paper by Dr. Chalmers, attention is directed more particularly to the measurement of the hardness of thin surface layers of metals and other materials. Details are given of a new method in which the reduction in optical reflectivity is determined when known quantities of sand are allowed to impinge on a surface under standardised conditions. Applications of this technique are described

in cases where other methods of measuring hardness are unsatisfactory.

The three papers presented by Mr. Phillips form part of a series of investigations on the constitution of aluminium alloys under conditions of metastable equilibrium, such as are likely to be met with in commercial practice. The work has been carried out in the Research Laboratories of the British Aluminium Co., Ltd., under the general supervision of Dr. A. G. C. Gwyer.

The first of these papers gives the results of a detailed study of the constitution of alloys of aluminium with 0-5% magnesium and 0-2% silicon. In this investigation the binary valleys bounding the primary aluminium phase field have also been redetermined. No attempt has been made to study equilibrium structures, or to determine systematically the solid solubility of the various constituents. The second paper gives the results obtained from a reinvestigation of the course of the binary valley between the aluminium and  $\text{FeAl}_3$  primary fields from the binary eutectic to the ternary eutectic, and those obtained from a study in detail of the range 0-2.5% iron, 0-5% magnesium. The third paper of the series is presented at some length elsewhere in this issue.

### Annual May Lecture

The 1942 May Lecture—the thirty-second of the series—is to be given to the Institute by Mr. W. T. Halcrow, M.Inst.C.E., on Wednesday, May 13, at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W. 1. The subject of the lecture is "Water Power and Its Application to the Production of Metals." The lecture will begin at 6 p.m., and light refreshments will be available at 5.30 p.m. in the basement of the Institution. Visitors' tickets admitting to the lecture can be obtained from Mr. G. Shaw Scott, 4, Grosvenor Gardens, London, S.W. 1.

### Magnesium Industry in the United States

THERE was an unprecedented demand for magnesium metal in the United States during 1940, and consumption increased to 75% over the previous year, according to data issued by the United States Bureau of Mines. Primary and secondary metal consumption accounted for 11,531,000 lb. of magnesium, of which 64% was used by manufacturers of magnesium-rich alloy castings, sheet and extruded products for aircraft, automobile and other industries. Magnesium-aluminium alloy manufacturers accounted for 31% of the total magnesium production, the major part of which must be credited to the aircraft industry. The balance of consumption was accounted for by such miscellaneous uses as a scavenger and deoxidiser in metallurgical processes, in the production of other magnesium-bearing alloys, and in the manufacture of chemicals, etc.

A remarkable fact in the analysis of the figure of 7,363,000 lb. of magnesium used in the manufacture of structural products is the loss of 1,979,530 lb. or 27% during the manufacturing processes owing to the susceptibility of the metal to oxidation at temperatures above its melting-point.

# The Influence of Molybdenum and Titanium Additions upon the Properties of a Chrome-Vanadium High-Speed Tool Steel

By D. W. RUDORFF, A.Am.I.E.E., M.Inst.F.

*Increasing attention is being given to modifications in the composition of various types of high-speed tool steels, and as a result of much study developments are continually being made. In this article the results of an investigation on the influence of molybdenum and titanium additions upon the properties of a chromium-vanadium high-speed steel are discussed and data given from tests.*

THE necessity for the conservation of materials in short supply, under present conditions, has led to considerable research on tool steels, and much progress has been made in the wider application of materials more readily available, but the need is ever present to obtain the utmost service from the modified compositions of tool steel, and to treat them in such a way that their service and life compares favourably with the compositions they are developed to displace. In this connection much attention has been given to high-speed tool steels, and in order to improve the cutting properties of the 11% Cr-2.2% Va type of high-speed steel, the influence of molybdenum and titanium additions upon the cutting qualities of this steel has recently been studied at the Leningrad Institute of Metals,\* the results of which are noteworthy. The analysis of the original steel and the two modifications developed are as follows:

	C.	Mn.	Si.	Cr.	Ni.	V.	Ti.	Mo.
Original Steel I ....	1.1-1.5	0.4	0.7-1.0	11-13	—	2.1-2.5	—	—
Steel II .....	1.0	0.32	1.08	11.85	0.3	2.25	—	3.8
" III .....	1.1	0.23	1.55	11.15	0.34	2.2	0.3	—

The various investigations were conducted on test-pieces of  $15 \times 20 \times 25$  mm.; while for the magnetometric tests pieces of 20 mm. diameter and 25 mm. length were used. These pieces were forged from bars 80 mm. square. The austenite content was ascertained by the usual magnetometric method. The pieces were brought to quenching temperature by preheating in three steps—that is, by first heating to  $650^{\circ}$ - $680^{\circ}$  C., thereupon to  $850^{\circ}$ - $870^{\circ}$  C., and finally to the desired hardening temperature. Quenching was done in oil. Tempering was carried out in an electric muffle furnace, and was followed by cooling in still air. Multiple tempering was carried out in periods of 1 hr. 15 mins., while for single tempers durations of 2 and 4 hrs. were chosen.

\* B. S. Shvirev and M. E. Goldvasser: Influence of molybdenum and titanium additions upon the properties of steel 2E, 172; *Stal*, p. 60, 1941.

Fig. 1.—Influence of hardening temperature upon hardness and percentage of residual austenite.

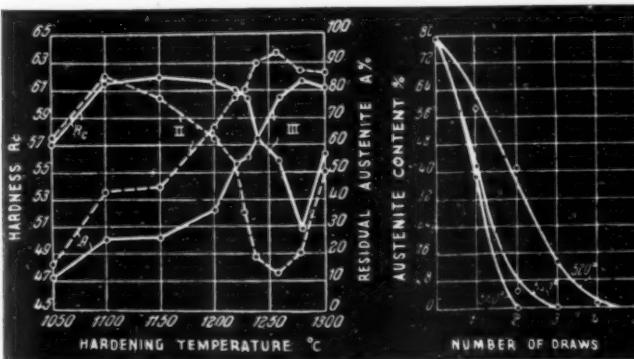
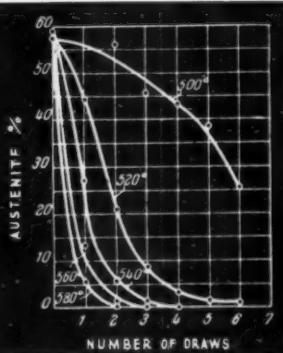
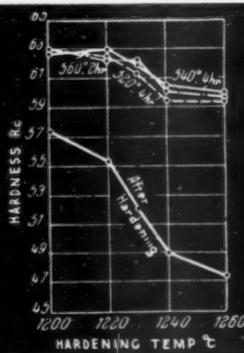


Fig. 3.—Residual austenite content of steel II versus number of draws at  $520^{\circ}$ ,  $540^{\circ}$ , and  $560^{\circ}$  C. (3-min. quench from  $1,230^{\circ}$  C.)

Fig. 4.—Hardness of steel II after quenching and after single draws of 2 and 4 hours' duration respectively.

Fig. 6.—Residual austenite content of steel III versus number of draws and temperature of draw.



With hardening from  $1,220^{\circ}$  C. both steels exhibited noticeable growth of the grains composed of austenite-martensite, reaching a maximum at  $1,230^{\circ}$  C. in steel II, and at  $1,260^{\circ}$  C. in steel III. These temperatures, therefore, were considered to constitute the upper limits of hardening. At these temperatures the amount of undissolved carbides reaches a minimum, the remaining carbides being displaced towards the grain boundaries. It was also observed that the employment of a 5-minute quench with hardening temperatures of  $1,230^{\circ}$  C., and  $1,260^{\circ}$  C. for steels II and III, respectively, leads to the appearance of ledeburite-like eutectic at the grain boundaries.

It is stated by the investigators that judging from micro-examination of steels II and III, the most satisfactory structures are obtained with hardening temperatures from

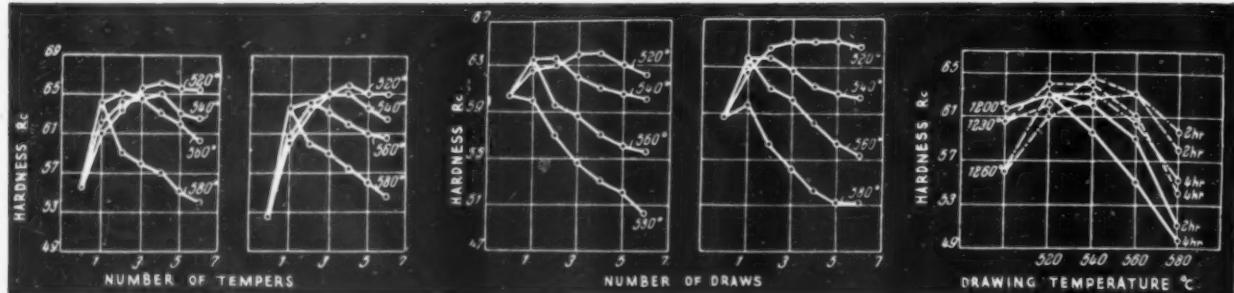


Fig. 2.—Influence of the number of draws upon the hardness of steel II.

Left : 3-min. quench from 1,220° C.  
Right : 3-min. quench from 1,230° C.  
Length of draw, 1 hour 15 minutes.

Fig. 5.—Influence of number of draws—of 1 hour 15 mins. each—upon hardness of steel III.

Left : 3-min. quench from 1,230° C.  
Right : 5-min. quench from 1,230° C.

Fig. 7.—Influence of temperature and length of single-draw upon hardness of steel III. (3-min. quench from 1,230° C.)

1,150°-1,220° C. It is also pointed out that both steels show a pronounced tendency towards grain-growth, even with comparatively low hardening temperatures. With regard to the carbides not going over into solid solution, even when quenching from high temperature, it must be assumed that these are carbides of vanadium or other complex carbides of great stability. With hardening from 1,050°-1,200° C., steel II exhibits a fine grained structure of great density, while with hardening from 1,300° C., a coarse and brittle structure, characteristic of overheated steel, is developed. Steel III retains a fine grain up to a hardening temperature of 1,230° C.; at higher temperatures it quickly assumes coarse-grained appearance and considerable brittleness.

Particular attention was paid by the investigators to the influence of repeated and prolonged tempering upon hardness, microstructure and residual austenite content. With quenching in the temperature range of 1,200°-1,300° C. the most advantageous temperature for the development of optimum secondary hardness was found to lie at 540° C. in the case of steel II. As Fig. 2 shows, a secondary hardness of 63.5-64 R<sub>c</sub> is achieved after two tempers, and, according to the graph reproduced in Fig. 3, the austenite is almost completely transformed. After drawing three or four times, the steel exhibited maximum secondary hardness, and a fine-grained martensite structure devoid of any visible spots of untransformed austenite. A tempering heat of 520° C. proved insufficient, since the appearance of secondary hardness became most pronounced only after four or five tempers, and this irrespective of the temperature of quench. With a drawing temperature of 560° C. maximum secondary hardness was reached with one single draw, further tempering leading to a sharp fall in hardness. This temperature cannot, therefore, be considered suitable. Tempering at 580° C. is likewise out of the question, as at this temperature the tempered material has hardly any resistance to softening. Pieces quenched from 1,240°-1,260° C. and tempered at 520°, 540° or 560° C. showed considerable stability. But owing to the appearance of the ledeburite-like eutectic and the attendant brittleness of the steel, this quenching range must be ruled out.

Tempering for 4 or 6 hrs. after quenching from 1,220°-1,230° C. gave satisfactory results as far as hardness is concerned (see Fig. 4), but the microstructure proved to be

extremely heterogeneous and unsuitable for cutting tools. The most advantageous tempering heat for steel III quenched from 1,200°-1,260° C. was found to be 520° C. At this temperature maximum secondary hardness was reached after three to four tempers. As shown in Fig. 5, this hardness approximates to 63-64 R<sub>c</sub>. This temperature of draw results in complete homogeneity of the structure and a practically complete decomposition of the residual austenite (as shown in Fig. 6).

Tempering of steel III at 560° or 580° C. results in a sharp decline in secondary hardness after the second temper (Fig. 5). The interrelationship between temperature of draw and hardness obtained with single draws of 2 and 4 hrs. duration, respectively, is charted in Fig. 7. Here it is seen that maximum secondary hardness was reached with a 1,230° C. quench (for 3 mins.) and with a draw at 540° C. lasting 2 hrs. But with this tempering range complete homogeneity of the microstructure was not reached, the latter containing patches of austenite together with a comparatively small amount of coarse dark-coloured needles of martensite and of carbides.

#### Forging and Annealing of Steels II and III

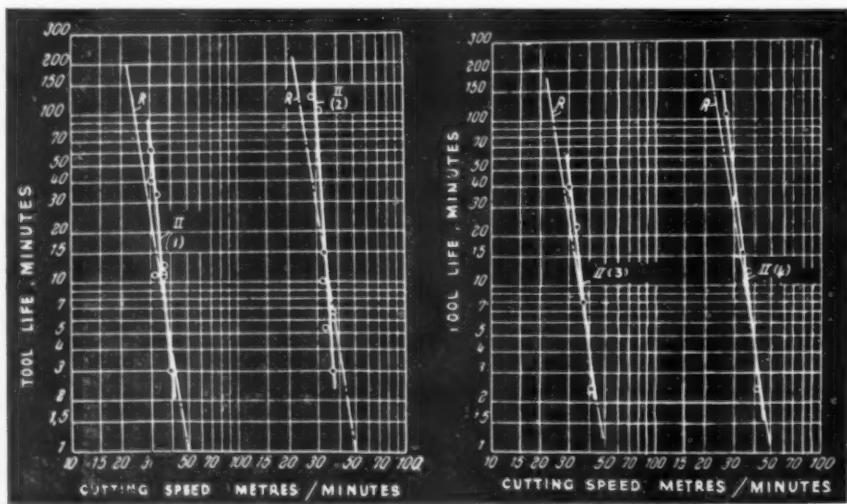
Forging tests conducted on steels II and III at temperatures ranging from 1,100° to 90° C. showed that the plasticity of these steels is distinctly inferior to that of standard high-speed tool steels. This lack of sufficient plasticity leads to the appearance of cracks during the forging process.

Fig. 8.—Tool life of steel R and steel II when cutting 5140 A.S.E. steel.

Left : Curve of steel II—temper (1)  
(see Table).  
Right : Curve of steel II—temper (2)  
(see Table).

Fig. 9.—Tool life of steel R and steel II when cutting 5140 A.S.E. steel.

Left : Curve of steel II—temper (3)  
(see Table).  
Right : Curve of steel II—temper (4)  
(see Table).



## HEAT-TREATMENT OF TOOLS OF STEELS II AND III MADE FOR TOOL LIFE TEST.

Temper No.	Steel No.	Temperature of Quench.	Length of Draw.	Temperature of Draw.		Length of Draw.	Temperature of Draw.	Length of Draw.	Hardness of Cutting Point, Rc.
				First Draw.	Second Draw.				
(1)	II	°C. 1,210	Mins. 3	540	H. M. 1 15	°C. 540	H. M. 1 15	540	63—63·5
(2)	"	1,210	3	560	1 15	560	1 15	560	62·0—63·0
(3)	"	1,230	3	540	1 15	540	1 15	—	63·5—64·0
(4)	"	1,230	3	560	1 15	560	1 15	—	64·5—65·0
(1)	III	1,230	3	520	1 15	520	1 15	520	63·5—64·5
(2)	"	1,230	3	540	1 15	540	1 15	—	62·0—63·0
(3)	"	1,230	4	520	1 15	520	1 15	520	63·0—65·0
(4)	"	1,230	4	540	1 15	540	1 15	—	61·0—62·0

During the forging of steel II it was noticed that this steel gives off comparatively large amounts of whitish vapours consisting of  $\text{Mo}_3$ . After forging, the test-pieces were annealed by heating to  $940^{\circ}\text{--}960^{\circ}\text{C}$ , at which temperature they were held for  $\frac{1}{2}$  hr., after that the temperature was lowered to  $800^{\circ}\text{C}$ . and annealing was continued for another 3 hrs. Cooling was carried out in the muffle.

## Cutting Tests Conducted with Steels II and III

The various hardening and drawing temperatures used in the determination of the tool life are enumerated below. The tool life data were established on the break-down basis, using the tool life of a standard high-speed tool steel "R" (with an analysis of 0·76 C, 4·1% Cr, 17·8% W, 0·99% V) as standard of comparison. The various test runs could be carried out only with single point cutting tools, as it proved impossible to use steels II and III as material for milling cutters, form tools, etc. This was, of course, due to the fact that these steels possess an inherent tendency to develop cracks when being forged into anything but the most simple of shapes. The material on which the cutting tests were

conducted was the well-known SAE 5140 steel (American Standard) of the following composition : 0·42% C, 1·0% Cr, 0·5% Mn, 0·2% Si, 0·03% P. Rods of 70 mm. diameter of this material were cut into lengths of 600 mm. and normalised; their hardness after thermal treatment was Hb = 207. The microstructure showed pearlite and ferrite deposited on the grain boundaries. The mechanical strength was 73·74·5 kg. per sq. mm.

The cutting tests were carried out in a capstan lathe, the cutting depth being

3 mm. and the feed being 0·4 mm. per revolution. It was found that the wear of the cutting edges of the tools made of steels II and III was generally very similar to that experienced with tools made of the aforementioned standard steel R. The results of the cutting tests are charted in the usual manner, the corresponding results obtained with steel R also being included. It was found that the best cutting properties obtained with steel II treated according to heat-treatment 1, 2 and 3, as described in the table given above. The appertaining graphs are reproduced in Figs. 8 and 9. Here it is seen that the tool life of steel II practically equals that of steel R. With regard to heat-treatment (4), it may be mentioned that the results shown in Fig. 9 could be obtained only with difficulty, as the tools showed a pronounced tendency to develop deep cracks and to lose the cutting point by chipping. The cutting tests carried out with the various tools of steel III were very disappointing insofar as the tool life proved to be only about one-third to one-fourth of that obtained with tools of steel R. These results need not, therefore, be reproduced here.

## Interpretation of Trials on Tool Steels

By Bernard Thomas, F.Inst.P., F.Inst.F.

**E**VEN in these days of stress and strain it is sometimes found possible to carry out trials of an assortment of steels in the "tool quality," in an endeavour to find an individual type more economic than another for some onerous duty. The object of the following remarks is to offer a guide in the interpretation of the results so obtained, as wide variation in cost values is apt to fog the issue of a decision. To the possibility of the favoured steel being in short supply, however, must be turned a diplomatic eye.

The first illustration chosen for the purpose is a trial on shear blades for a hand-shearing press, where large quantities of 0·50% carbon-steel plates, measuring  $\frac{1}{8}$  in. in thickness, were required to be cut. Five types of steel were employed, typical analyses of which are as given in Table I.

TABLE I.  
TYPICAL ANALYSES OF STEELS USED.

Element.	A %	B %	C %	D %	E %
Carbon .....	0·90—1·0	0·42—0·46	0·55—0·65	0·42—0·46	0·40—0·45
Manganese .....	0·40—0·50	0·30—0·40	0·50—0·60	0·50—0·80	0·20—0·40
Silicon .....	0·25—0·30	0·60—0·80	1·4—1·6	1·0—1·1	0·20—0·40
Chromium .....	—	1·2—1·4	0·70—0·80	0·60—0·70	1·7—1·90
Tungsten .....	—	2·2—2·4	—	—	1·8—2·0
Vanadium .....	—	0·10—0·15	—	—	0·15—0·25
Nickel .....	—	—	2·8—3·2	—	—

Steel A was of an excellent quality crucible cast manufacture; Steel B, a tungsten-chrome with medium silicon. Steel E was similar, but with lower silicon, while C and D were plain silicon-chromes, with somewhat different carbon contents. Originally, the crucible cast steel A had been used exclusively for the work involved, but it was felt that with the wealth of alloyed material available, some

such latter was capable of yielding improved results. The carbon steel was regarded, therefore, as a basis for comparison throughout.

Three pairs of blades were made from each type of steel and placed into service on work of exactly similar character, recordings of work produced being kept meanwhile.

A pair of blades after a certain number of cuts requires regrinding, due either to normal wear or chipping, and the frequency of such regrinding, coupled with the amount of steel found necessary to remove, serves as an indication of the quality. Heavy grinds reduce the sum total of regrinds possible before reaching the holding-down holes, so that the potential total work output may be lower accordingly.

In Table II are listed the average grinds necessary, together with total counts obtained, placed in order of their superiority, with the original crucible quality, Ref. A, as the basis, placed first, for ease of comparison. On this showing Steel B should be the obvious choice for the operation, but this is where a cross analysis becomes necessary for economic reasons, always providing that the exigency of circumstances does not overrule all cost consideration.

TABLE II.  
COMPARISON OF GRINDS NECESSARY AND OUTPUTS OBTAINED

Steel.	Average Grinds,	Total Output in Thousands,	Increase or Decrease.	
			Output in Thousands,	Percentage.
A ..	11·7	42·6	..	Basis
B ..	11·0	50·6	8·0	18·8 Increase
C ..	11·0	50·4	7·8	18·3 "
D ..	12·0	45·5	2·9	6·8 "
E ..	11·0	35·9	6·7	15·8 Decrease

As indicated earlier, the steels used differed widely in cost, and it becomes necessary to set same down for examination, which is done in Table III.

TABLE III.  
PURCHASE VALUES OF STEELS USED IN TRIAL.

Steel.	Type.	Cost per Cwt.
A	Crucible Cast	147/-
B	Tungsten-Chrome-Silicon	128.6
C	Silicon-Chrome	137/-
D	Silicon-Chrome	89/-
E	Tungsten-Chrome	108/-

If the total output from the blades as shown in Table II be taken and adjusted proportionately to suit a purchase basis of 100s. per cwt., the true picture is then presented. In Table IV this has been done by increasing all counts in the case of steels costing less than 100s. per cwt., and reducing those for the others where such basis has been exceeded. In the same table, the improvement of the various alloy types over the crucible quality is further demonstrated by output figures and percentages on the 100s. per cwt. steel cost basis.

An entirely different complexion is now revealed by the figures in Table IV. Steel D emerges as considerably more economic than the crucible type, displacing B in spite of the high total count of production yielded by the latter. Steel C, which ran B closely in total output, falls abruptly to the bottom of the list by reason of its high purchase cost. This relieves E of the wooden spoon as the medium purchase cost is of assistance when converting to the 100s. per cwt. basis.

TABLE IV.  
OUTPUT COMPARISON REVISED TO 100 CWT. STEEL COST BASIS.

Steel.	Output at Purchase Price, Thousands.	Output at 100/- cwt. Basis, Thousands.	Improvement over Steel A.	
			Output Thousands.	Percentage.
A	12.6	28.9	—	—
D	45.5	51.2	22.3	77.2
B	50.6	39.4	10.5	26.7
E	35.9	33.2	1.3	14.9
C	50.4	32.1	3.2	11.1

In a trial of this nature the economic interests are served, but at the same time the information given is such as to

enable highest outputs to be obtained when necessary, regardless of cost.

The second illustration chosen concerns hot die steels. With such steels the price is usually in the neighbourhood of 3s. per lb., which is sufficient to cause some potential users to lose interest. The remarks which follow may help to overcome the prejudice.

In a small hot drifting operation, where countless thousands of articles received attention, it was the practice to use an ordinary 0.60% carbon steel costing less than 2d. per lb. The tool was a small insert die weighing, when ready for service, 6 lb. The average output from these inserts was 4,200, and the life barely four shifts.

After reviewing the alloys available, many trials were made until finally the solution appeared to lie with a standard hot-die type of 9-10% tungsten and 3.5-4.2% chromium. Superficially, however, at 3s. per lb., while ten times the life was possible from the die, the steel cost was twenty times that used previously, and was therefore thought in certain quarters to be uneconomic. A study of the schedule in Table V, however, may clarify the point.

TABLE V.  
SCHEDULE OF INSERT DIE COSTS AND COMPARISONS.

Item.	Steel A.	Steel B.
Type	Plain Carbon, 1½d. lb.	Tungsten Chrome, 3/- lb.
Cost	£ s. d.	£ s. d.
Cost of insert blank (weight 14 lbs.)	0 2 0½	2 2 0
Die sinking	3 0 0	3 0 0
Hardening and tempering	0 2 6	0 2 6
Total cost when ready for use	£3 4 6½	£5 4 6
Average output	4,200	41,400
Output per £1 of die cost	1,302	7,940
Ratio C/W Cr	1	6.1

In plain words, despite the fact that the hot-die steel was more than twenty times the cost of the carbon variety, the output per £1 of die when ready for service was more than six times that of the cheaper type.

The moral to be drawn from the foregoing is that one should neither pay too much attention to initial costs of alloy steels, or lose sight of the essentials which need to be included in comparisons before correct interpretation can be made.

## Research Activity in Swedish Steel and Mining Industry

**I**N a recent lecture the head of the technical department of the Swedish Ironmasters' Association, Mr. M. Tigrerschiöld, gave some interesting information about recent Swedish researches in the domains of the steel and mining industries.

The Swedish Ironmasters' Association is a representative institution for the Swedish iron and steel trade, which was founded in the 18th century chiefly for safeguarding the financial interests of the trade at that time. In modern times, and especially since the beginning of this century, the Institution has devoted itself largely to metallurgical and allied research in co-operation with its members, the principal Swedish mineowners and iron and steel works. This activity, Mr. Tigrerschiöld said, has developed into a strong organisation which has proved of especially great benefit during the present crisis. At least half of the research work now conducted by the Institution is concerned with problems created by current exceptional requirements of the iron and steel trade. Thus, at a very early stage, trials were instituted with furnaces of new types for using wood instead of coal, which made it possible for the steel works to carry through quickly and efficiently the necessary adaptation measures when the Swedish State Fuel Commission about a year ago enjoined them to replace coal to at least 50% by wood. The Swedish metallurgists have also succeeded in evolving new types of steel and new production methods, which have brought about the necessary reduction in the use of alloys. The researches under this head are, however, far from completed, and remain one of the most important tasks, the lecturer said. In many cases, how-

ever, the results so far attained have been so favourable that the researches carried on by the Institution must be regarded as a very good investment for the participating works.

The decarbonisation process in steel-making has been made clear through an exhaustive investigation of this subject. The possibility of reducing the consumption of fuel by Swedish blast-furnaces has likewise been thoroughly investigated. Experiments with a new method of iron-making—dry decarbonisation of granulated pig iron, according to a method invented by the Swedish engineers, Rennerfelt and Kalling—have been wholly conducted at the expense of the Institute, and the method has now been adopted by three Swedish ironworks with very good results. Furthermore, extensive investigations, which have won international recognition, have been performed on ingots of rimmed steel. These investigations have become of fundamental importance for the advancement of the quality of that kind of steel.

The mining committee of the Institute has *inter alia* devoted much work to promoting high-pressure drilling, which has signified a great saving in operating costs at the mines that have adopted this method. Good economical results have also accrued from tests with various strong explosives, this Swedish steel expert further stated. Very big contributions towards solving the current problems within the mining and steel trades had also been made by a number of Swedish enterprises through their own researchers.

# Recovering Gold From Disused Melting Crucibles

By C. C. Downie

*In recent years the value of gold has greatly increased, and every effort is made to ensure its maximum recovery. The author previously discussed the economical reduction of the poorer classes of gold residues;<sup>1</sup> in the present article he deals with the recovery of gold from disused melting crucibles. Although not so searching in a molten state as some of the bronzes, gold penetrates the interstices and fissures which develop in crucibles in service, and it is the recovery of this gold to which attention is directed.*

**A**s an appreciable amount of gold accumulates in the linings of old melting pots in large refineries, every effort is made to reclaim the valuable contents and place them on the market with the least delay. Plumbago crucibles have well-made linings, but after repeated use small fissures and cracks appear, and despite the great specific gravity of gold—namely, 19.5—minute particles are retained in this lining. Whilst the ramifications of the cyanide process are considerable, it is doubtful if modifications of this system could be economically applied to recovering the gold values from these linings. This is borne out by the fact that many of the large firms engaged on cyanide practice do not treat their old crucibles, but dispose of them to gold refiners who deal with more concentrated products. It may appear surprising that work of this nature is not carried out on the spot, but strange though it may appear, almost the entire bulk of the old pots used in refining gold on the Rand and other African deposits is shipped—or was before the outbreak of war—to this country or to American smelters. As a rule, the accumulation of old pots is reduced to a fine powder by grinding, and concentrated to some extent by passing over jigs and concentrating tables, but no attempt is made to separate out the gold in this manner. In some refineries, a record is kept of the number of heats which each pot can successfully melt, without showing any disposition to develop fine cracks, whilst efforts are made to ascertain what average content of gold remains in the linings.

Some makes of crucibles appear to withstand the melting of gold better than others, probably due to the type of graphite used, but this is also influenced by the chlorination or other final refining treatment accorded. When gold has reached the stage of melting into bars, it is expected to be practically free from impurities, and at the most usually only contains a few parts per thousand. Throughout the refining of gold and its associated precious metals, a certain absence of scientific principles is almost invariably present, and this can to some extent be accounted for by the desire to get the refined bars disposed of as rapidly as possible, to avoid loss of bank interest. Thus examples can be cited in actual practice of adding nitre and other highly oxidising fluxes to the gold contents of plumbago crucibles, which latter, in the ordinary way are incapable of withstanding the attack.

Although clay pots are perhaps better suited for this purpose, the risk of the linings allowing the heavy metal to pass through, and also cracking seriously, has prevented them being substituted.

Refining gold with bisulphates, boric acid and phosphoric acid, and these acids with oxidising agents, ammonium chloride, mercuric chloride, sulphur, iron, and common salt, etc., have all been more or less abandoned nowadays, and except the addition of nitre, or chlorine gas, receive no outside agents. With retorted gold, porous material has to be dealt with, and as the surface exposed is large, this acted as an incentive to use fluxes from the commencement

so that they reacted while the temperature was rising, whilst the lining of the pot suffered accordingly. Gold precipitated from rich solutions by ferrous chloride and similar agents reveals the same porous condition, but the damage done to melting crucibles was so considerable, when appreciable quantities of gold had to be dealt with, that additions were only made at the final stages—i.e., just prior to pouring into bar moulds. As gold precipitated in this manner contained a few parts per thousand of iron, a final addition of nitre to oxidise it was persevered with until quite recently, when chlorination on a modified scale was substituted. Both reagents make incisions on the linings of the pot, and leave slight interstices where gold particles can lodge.

## Fluxes Used to Remove the Carbon

After the crucibles have been used for a fixed number of heats, they are laid aside for grinding and partial concentration, and the rich mass resulting contains all the heavier particles, and frequently reaches some 30 oz. of gold per ton. The bulk of the concentrates consists of clay still retaining some graphite, which at one time was considered a difficult material to smelt directly. Earlier efforts at directly recovering gold consisted of first roasting the mass on mechanically operated roasting furnaces, to burn out the carbon, followed by fusing it with fluxes, but when not properly fluxed, the alumina content tended to produce a viscous slag, and this appeared to discourage any continuance of the process. The roasting to remove carbon was a slow and laborious process, and even the best operations of the mechanical hearth seldom exceeded 1 cwt. of carbon-free residues per hour. A process was then copied from methods used by firms engaged on smelting base metal residues containing carbon, utilising oxidising fluxes, which thus obviated the need for any preliminary roasting. It may appear remarkable that work of this kind was not adopted at the site of the African goldfields, since the transport, careful packaging, and insurance had to be paid to despatch the residues some thousands of miles, and can only be attributed to a certain lack of enterprise. The residues as received from the Rand, and other gold districts, takes the form of a fine dark powder which is accurately sampled, and assayed prior to smelting.

The mass is then mixed with fluxes, which act in the capacity of oxidising agents, but preferably those which already contain some small content of precious metal, since it is considered uneconomical practice to include what is termed "barren" material. These fluxes are represented by iron oxide residues, lead sulphate precipitate, litharge, and limestone, whilst periodically flue dusts when available are included, and also the remains of furnace bottoms.

As examples of the gold contents, the following will give some indication. The iron oxide residues which were recovered from the wet extraction of roasted mattes averaged 12.5 oz., lead sulphate 1 oz., litharge 5 oz., flue dust 2 oz., and furnace bottoms anything from 4 oz. to 80 oz. of gold per ton.

Thus, apart from utilising the oxidising qualities of these

<sup>1</sup> "Direct Blast Smelting of Poor Gold Residues," METALLURGIA, Oct., 1937, pp. 205-207.

fluxes, their respective gold contents were recovered at the same time, with the notable exception of the limestone, which was the only "barren" material included. Pyrites which are preferably gold-bearing, may or may not be included at this stage, depending on the fusibility of the resulting mass. The proportion of ground crucible residues has to be varied according to the carbon content, and where the latter is excessive there is no option but to use a smaller charge, so as to allow oxidation to proceed unhampered.

The residues and fluxes are intimately mixed and ground to fine powder, followed by adding water-glass as the binding medium, and forming into briquettes, with the assistance of a small briquetting press. No attempts are made to follow briquetting practice as adopted on systematic lines in large smelters, and the damp, freshly pressed briquettes are simply placed on trucks and led to a flue where they are left until dry. Tests are made of the fusibility of the briquettes, before charging into the smelting furnace, by trying samples, and should refractory tendencies appear, succeeding briquettes are made with the addition of some easily fusible slag.

### Smelting the Briquettes

The briquettes are then charged into a small water-jacketed blast-furnace, which has a capacity for working a total of about 100 tons per week, and which uses foundry coke as the fuel. This furnace commences operations by working foul slags from other smelting processes, until a good heat has been raised, after which the briquettes are added in increasing proportions. Briquettes eventually reach a ratio of about equal proportions to that of the slag, which ratio is dependent upon the percentages of carbon and alumina, and this is maintained until the final charge which is usually run down with slags practically alone, or with the addition of some very poor gold-bearing material. Although metallic lead is added to assist the picking up of gold, this is not so satisfactory as the use of increased litharge, which through reduction is produced in much finer condition, and is almost invariably more effective. What sulphur is present from the lead sulphate and raw materials forms a matte, and if too little matte is tapped there is the possibility of it being unduly rich, whereby the associated slag is frequently rendered foul. For this reason it is often necessary to increase the sulphur content by adding preferably gold-bearing pyrites, or failing this, sodium sulphate. Sodium sulphate, however, holds the advantage that during its reduction to sulphide more of the carbon from the crucible residues becomes oxidised, and thus assists the rapid working of the charges. The products are a poor slag, matte, and lead, which contains almost the entire gold content. The matte, which acts as the intermediate medium, can have its iron, copper and lead proportions manipulated, apart from its total volume, so that the slag is sufficiently poor to be disposed of as waste, although on occasions it was known that lithium was present.

Poor slags rarely contained more than 0.041 oz. of gold per ton, but rich slags reached as much as 0.13 oz. per ton, and had to be returned to the furnace for remelting. The gold content of the matte averaged about 6 oz. gold per ton, whilst the lead contained anything from 20 oz. to 40 oz. of gold, entirely depending on the gold present in the original crucible linings. This lead is cleaned by skimming when, as an average figure, the gold is concentrated to 60 oz., after which it is transferred to a "test" or cupellation hearth, followed by one of the usual refining processes. It should be understood that the above example tends to poor Rand crucible residues, and that others have given lead which amounted to over 100 oz. per ton. This concentration can be varied by the amount of litharge, which is reduced, and in some cases where it is unduly poor the cast pigs are simply passed repeatedly through the furnace, so that they become correspondingly enriched in gold, but this practice, if carried too far, tends to make the slags foul.

COMPOSITION OF BRIQUETTES.

	1 %	2 %	3 %	4 %	5 %
Rand sweep .....	28	31	31	29.5	45
Other "sweeps" and residues .....	17	8	6	—	—
Flue dust .....	8	7.5	6	8	7.5
Works' excavations .....	7	12.5	13	20.5	—
Rich furnace slags .....	8	7.5	8	8	—
Crude works' litharge .....	3	—	2	1	—
Limestone .....	16	18	17	19	22.5
Iron residues (from wet extraction) .....	13	15.5	17	14	25.5
	100	100	100	100	100

NOTE.—Lead sulphate precipitate is included in flue dust.

No. 1.—A common example.

No. 2.—Sufficient lead in charge to omit litharge.

No. 3.—Similar composition requiring lead, and more iron oxides for fluxing.

No. 4.—Composition used after vacation periods, when much gold-bearing works' excavations are available, necessitating higher limestone content.

No. 5.—Composition when no outside "sweeps" or works' excavations, etc., are available, and when all foul slags have been worked off, necessitating greatly increased limestone and iron oxides for fluxing.

### Concluding Observations

Aluminous slags require to be kept within fixed ratios with the lime, silica, and ferrous oxide, in order to ensure a thin and easily fluid slag, and assistance has been gained in this work from researches carried out with iron blast-furnace slags, which have already been published, and need not be repeated. The chief difference is the carbon present, which tends to slow down the reactions, and which on occasions has been found to some small extent floating on the surface of the slag when tapped. A point worth noting is that whereas in some smelting operations an infusible slag can be rendered fluid by simply increasing the temperature, such a measure is not permissible with the foregoing work, since this would mean an unduly increased volatilisation of the lead, and, strange though it may appear, this has been known to mechanically carry off gold to the flue dust. The work was immeasurably assisted by systematic oxidation of the carbon, and accurate fluxing of the alumina content derived from the clay of the pots. In the trade, the ground Rand pots and old crucible residues from other sources go under the category of "sweep," which is apt to be a misleading term. The tonnage of such "sweep" from the foregoing sources is greater than that of all other residues, although the latter may be richer in gold content, since considerable numbers of pots are utilised annually, and thus it represents an important source of raw material for the gold refiner. Once the fluxing conditions have been stabilised, the process is very simple and straightforward, as the high specific gravity of the gold ensures it sinking comparatively easily, and combining completely with the lead.

### Code for Protection of Foundries

RECENTLY the United States Government requested the foundry industry to draft a set of rules and recommendations to be used as a guide in providing safeguards for foundries during war-time, so that the maximum operating capacity will not be endangered. In answer to this request, the American Foundrymen's Association has formed a committee to draft such a code of rules for the protection of foundries and properties in war-time. The committee will function under the Safety and Hygiene section of the American Foundrymen's Association, and will be under the chairmanship of James R. Allan, chairman of the A.F.A. Industrial Hygiene Codes Committee. This committee has had extensive experience in the preparation of foundry industry codes, having produced five codes of recommended good practice.

Until this code of rules is available, Mr. Allan suggests that each foundryman study his individual problems in order to guard against sabotage and fifth column activities. He recommends that foundrymen consult their local branch of the Federal Bureau of Investigation, and that they give the subject earnest consideration, so that they will be better prepared for a code of rules when it becomes available.

# The Constitution of the Aluminium-Rich Alloys of the Aluminium-Nickel-Iron and Aluminium-Nickel-Silicon Systems

By H. W. L. Phillips, M.A.

*Results are given of a study of the alloys of aluminium, nickel and silicon over the range nickel 0-5, silicon 0-12%, and the alloys of aluminium, nickel and iron over the range nickel 0-3, iron 0-3%. The position of the binary eutectic of aluminium and  $\text{NiAl}_3$  was also redetermined. The work is described by Mr. Phillips in a paper presented at the recent general meeting of the Institute of Metal and given here in a substantially abridged form.*

**T**HIS investigation is one of a series on the constitution of aluminium alloys under metastable conditions, such as are likely to be met with in commercial practice. It deals with alloys of aluminium, nickel, and silicon over the range nickel 0-5, silicon 0-12%, and with the alloys of aluminium, nickel and iron over the range nickel 0-3, iron 0-3%. The work was carried out in the Research Laboratories of the British Aluminium Co., Ltd., under the general supervision of Dr. A. G. C. Gwyer, and the results presented at the annual general meeting of the Institute of Metals, held this month. Previous papers have dealt with the constitution of alloys of aluminium with silicon and iron<sup>1</sup>; silicon, iron and copper<sup>2</sup>; magnesium and silicon<sup>3</sup>; and magnesium and iron.<sup>4</sup> The object of this work is to obtain the limits of occurrence of the various phases under conditions of metastable equilibrium, to determine the temperatures at which these phases separate or react, and to study the extent of departure from structural equilibrium.

## Binary Alloys of Aluminium and Nickel

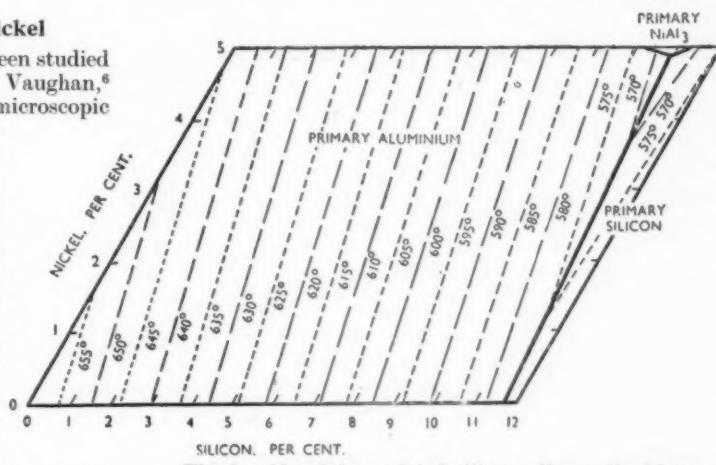
The constitution of these alloys has recently been studied by Fink and Willey,<sup>5</sup> and by Alexander and Vaughan,<sup>6</sup> using the methods of thermal analysis and microscopic examination, and also by Bradley and Taylor,<sup>7</sup> using X-rays. It may be taken as established that aluminium forms a eutecticiferous series with the intermetallic compound  $\text{NiAl}_3$ , with extremely limited solid solubility at either end. Bradley and Taylor<sup>8</sup> state that  $\text{NiAl}_3$  is orthorhombic, containing 16 atoms per unit cell, and remains stable with a slight excess of aluminium. Fink and Willey give the solid solubility of nickel in aluminium as 0.05% at the eutectic temperature (639.9°C.), falling to 0.0025% at 450°C. They place the eutectic composition at 5.7% nickel, a figure which is consistent with the observations of Alexander and Vaughan. In discussing the latter paper, Gwyer mentioned that the eutectic point had been determined in the laboratory of the British Aluminium Co., Ltd., and found to lie at 6.39% nickel and 640°C.

In the present investigation work on the binary alloys has been limited to a determination of the liquidus and solidus temperatures of alloys containing 0-10% nickel. They were prepared, in steps of 0.5-1.0% of nickel, from aluminium of 99.85% purity, analysing: iron 0.08, silicon 0.07, copper and manganese <0.01%; and from carbonyl nickel of 99.9% purity. In view of the discrepancy in the figures published for the eutectic composition, the work was repeated, in steps of 0.25%, using super-purity aluminium, analysing: iron 0.001, silicon 0.001,

copper and manganese <0.001%, aluminium 99.997% (by difference). Cooling curves were taken on 200-grm. quantities, using a platinum/platinum-rhodium thermocouple in conjunction with a Carpenter-Stansfield deflection potentiometer. The composition of the eutectic was first determined approximately by finding the compositions at which the last traces of primary aluminium disappeared and at which  $\text{NiAl}_3$  first became primary. The limits were thus found to be 6.23-6.59% nickel. The presence of primary aluminium dendrites in an alloy containing 6.12% nickel is illustrated. Eutectic areas of these microsections were next analysed, using the dimethylglyoxime method, and the composition was found to lie between the limits 6.36 and 6.40% nickel. The mean of the figures obtained, 6.39%, was that quoted by Gwyer.

## Ternary Alloys of Aluminium, Nickel, and Silicon

This system has previously been investigated by Fuss,<sup>10</sup> Hisatsune,<sup>11</sup> Otani,<sup>12</sup> and Weisse.<sup>13</sup> These authors agree in



*Scope of Investigation.*—The present investigation covers the range nickel 0-5, silicon 0-12%. The silicon used analysed : iron 1.5, aluminium 0.42, titanium 0.04, silicon 98.04% (by difference). Aluminium of 99.85% purity or super-purity was used as a basis.

*Micrography of the Alloys.*—Silicon is readily distinguished by its characteristic colour and habit, and needs no etching reagent.  $\text{NiAl}_3$  is pinkish-grey in colour and often crystallises in a script-like form. It is so different from silicon in its colour and relief that etching is rarely necessary ; either sodium hydroxide or hydrofluoric acid may be employed if desired, both tinting it brown.

*The Liquidus Surface* (Fig. 1).—Two primary phase fields are present, due to the aluminium-rich solid solution and silicon, respectively. They are separated by a binary valley which terminates at the ternary eutectic point. The composition of the ternary eutectic was found by microscopic examination, followed by the chemical analysis of eutectic areas of the microsections, the silicon being estimated by the Regelsberger method.<sup>14</sup> The figures obtained were nickel 4.90, silicon 10.98%, with freezing-point 567° C.

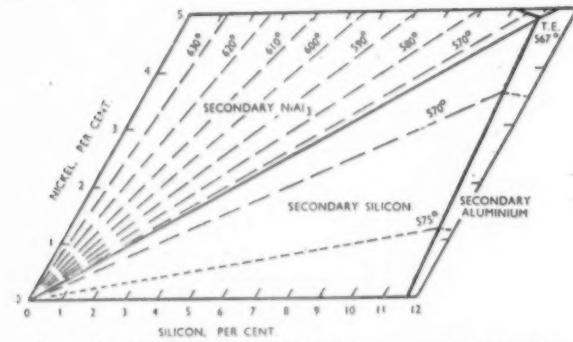


Fig. 2.—Aluminium-nickel-silicon alloys : secondary surface.

*The Surface of Secondary Separation* (Fig. 2).—This calls for very little comment. The surfaces are regular and the "line of secondary crossings," separating the two secondary fields, is rectangular, running from the origin to the ternary eutectic. The curvature of the isothermal is very slight, indicating little change in the composition of the primary phase during solidification.

*The Solidus.*—No diagram is needed. With the exception of a very narrow strip adjacent to the aluminium-silicon axis, and an even narrower strip adjacent to the aluminium-nickel axis, the solidus is coincident with the ternary eutectic plane. Silicon can be detected, though with some difficulty, in slowly cooled alloys containing 0.1% of silicon irrespective of the amount of nickel present. The  $\text{NiAl}_3$  constituent can readily be identified at 0.05% of nickel, and its solubility appears to be unaffected by the addition of silicon.

*Constituents Present in the Solid State.*—With the exception of the alloys containing less than 0.1% of silicon, three constituents occur over the whole range investigated. Figs. 3 and 4 are included as typical sectional diagrams. They show the general trend of the surfaces of separation, but do not call for detailed comment.

#### Ternary Alloys of Aluminium, Nickel, and Iron

These alloys have been studied by Fuss<sup>15</sup> and by Bradley and Taylor.<sup>8</sup> Fuss, using thermal and micrographic methods, found that the section  $\text{FeAl}_3-\text{NiAl}_3$  was quasi-binary, and that the three constituents, aluminium,  $\text{FeAl}_3$ , and  $\text{NiAl}_3$  formed a ternary eutectic containing nickel 5.5, iron 1.5% and freezing at 630° C. He found no evidence of ternary compound formation, and no evidence of solid solubility of nickel in  $\text{FeAl}_3$  or of iron in  $\text{NiAl}_3$ . These conclusions were not substantiated by the work of Bradley and Taylor, who, using X-ray methods, found that  $\text{FeAl}_3$

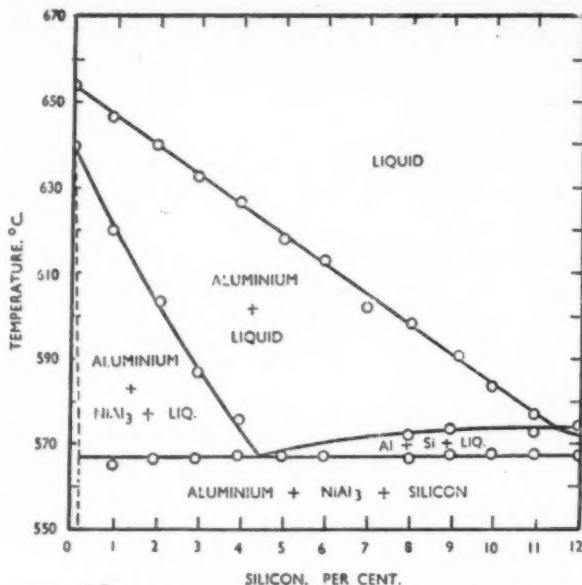


Fig. 3.—Aluminium-nickel-silicon alloys : section at 2% nickel.

decomposes on slow cooling into a mixture of  $\text{Fe}_2\text{Al}_7$  and  $\text{Fe}_2\text{Al}_5$ . The former is capable of dissolving a considerable amount of nickel, probably by the substitution of nickel for iron in the lattice.  $\text{NiAl}_3$  is capable of dissolving iron to a limited extent, again by substitution. Their diagram is shown in Fig. 5. The two-phase field ( $\lambda_1 + \epsilon$ ) thus extends only over a portion of the  $\lambda - \epsilon$  section, and not over the whole of it, as postulated by Fuss. Towards the aluminium corner a new constituent,  $\rho$ , appears, with characteristics of the alloys in which it occurs. Near the aluminium corner, five phase fields are shown, bounded by straight lines running to the apex. Whilst this is in accordance with theoretical requirements, it is to be noted that

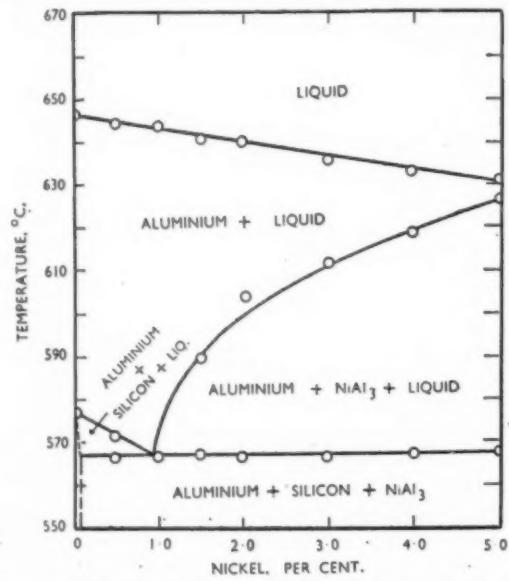


Fig. 4.—Aluminium-nickel-silicon alloys : section at 2% silicon.

no alloys having more than 80 atomic % aluminium were examined, and it is by no means certain that the phase boundaries would be rectilinear or would run to the apex under conditions likely to be met with in practice, where true structural equilibrium is unlikely to be attained.

*Scope of the Investigation.*—The constitution of the alloys has been studied in detail over the range iron 0-3, nickel 0-3%, and, in addition, the binary valley bounding

<sup>14</sup> British Aluminium Co., Ltd., (Publ.), 1941 (399), p. 16.

<sup>15</sup> V. Fuss, loc. cit., p. 140.

the primary aluminium phase field has been followed as far as the ternary eutectic point. The materials used were aluminium of 99.85% purity and super-purity, carbonyl nickel, and Armco iron, added as a hardener containing 10% of iron.

*Micrography of the Alloys.*—In addition to the binary

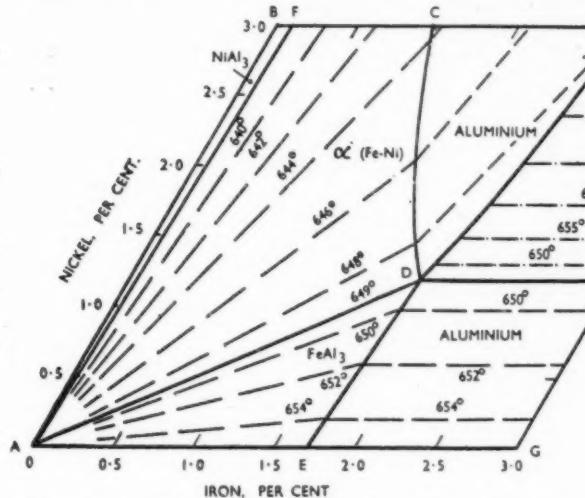


Fig. 7.—Aluminium-nickel-iron alloys : surfaces of secondary separation.

constituents  $\text{FeAl}_3^*$  and  $\text{NiAl}_3$ , a third constituent was found to occur over the whole range investigated. It is probably a ternary body, and may be identical with Bradley's  $\rho$ . Since its identity has not been definitely established, for the present it will be termed  $\alpha$  (Fe-Ni).

$\text{FeAl}_3$  occurs in the form of prismatic crystals or needles. It is lavender grey in colour and thus differs from the two nickel-bearing constituents, both of which are pinkish-grey. The latter occur as prismatic crystals when primary, and frequently adopt a script form in eutectic areas. Both are attacked by sodium hydroxide or hydrofluoric acid, and whilst the degree of attack tends to be irregular,  $\alpha$  (Fe-Ni) is usually the more deeply etched of the two.

primary fields, due to aluminium,  $\text{FeAl}_3$ , and  $\alpha$  (Fe-Ni). The primary aluminium field is bounded by two binary valleys, E D and D C. The former runs from the aluminium- $\text{FeAl}_3$  binary eutectic E (1.7% iron, 638° C.), to the invariant point D (nickel 1.2, iron 1.8%, 649° C.), and represents the separation of the binary complex of alu-

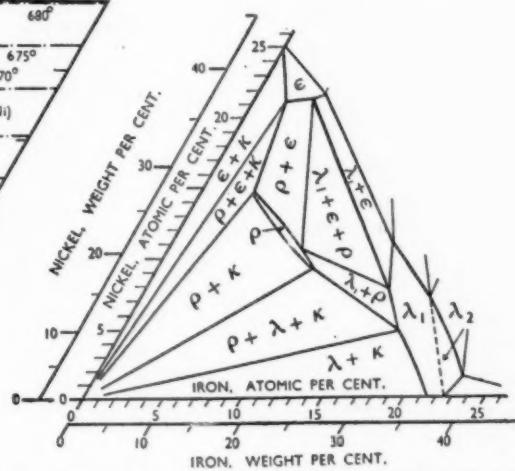


Fig. 5.—Aluminium-nickel-iron alloys : phases present in the solid state, according to Bradley and Taylor.<sup>5</sup>

minium and  $\text{FeAl}_3$ . At D the solid  $\text{FeAl}_3$  reacts peritectically with the liquid, and  $\alpha$  (Fe-Ni) is formed; three solid phases are present, together with liquid, and the system becomes invariant. Along D C the separation is that of the binary eutectic complex of aluminium, and  $\alpha$  (Fe-Ni); this valley terminates at the ternary eutectic point, at which the phases present are  $\alpha$  (Fe-Ni), aluminium, and  $\text{NiAl}_3$ . The composition of the ternary eutectic was determined by analysing eutectic areas of suitable micro-sections, and was found to be nickel 6.27, iron 0.28%. Its freezing-point was 638° C. The iron content was determined by titration against titanous chloride. These values differ appreciably from those reported by Fuss.<sup>10</sup>

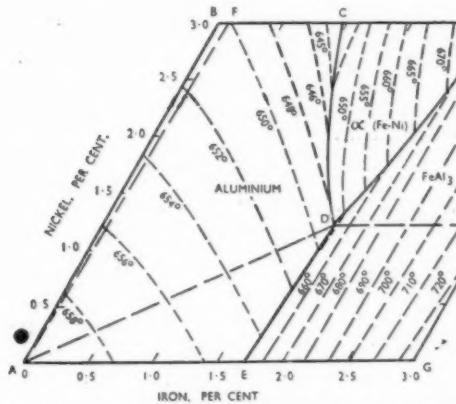


Fig. 6.—Aluminium-nickel-iron alloys : liquidus surface.

In alloys in which, broadly speaking, the content of iron exceeds that of nickel,  $\alpha$  (Fe-Ni) is formed as the product of a peritectic reaction between  $\text{FeAl}_3$  and liquid. Complete or partial envelopment of the  $\text{FeAl}_3$  is common, and the reaction rarely proceeds to completion. Elsewhere  $\alpha$  (Fe-Ni) separates independently from the melt. When primary, it tends to form a few large crystals rather than many small ones, and, being brittle, is thus a potential force of localised weakness in cast alloys.

*The Liquidus Surface* (Fig. 6).—This consists of three

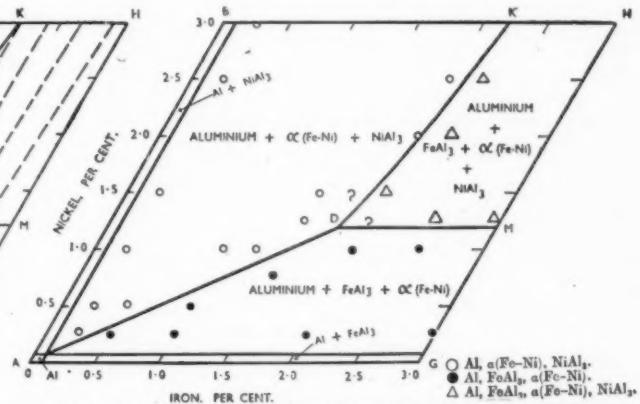


Fig. 8.—Aluminium-nickel-iron alloys : constituents present in the solid state.

The  $\text{FeAl}_3$  and  $\alpha$  (Fe-Ni) fields slope steeply, and are separated by the peritectic line D K; this line indicates a change of slope and not a valley. Although  $\text{FeAl}_3$  is subject to undercooling, its primary arrests were not difficult to detect on the cooling curves, and their temperatures were reasonably consistent.

*Reactions Below the Liquidus.*—The reactions occurring below the liquidus are somewhat complicated owing to the lack of attainment of equilibrium, and can perhaps best be visualised with the aid of diagrams showing the liquidus (Fig. 6) and the secondary separation surfaces (Fig. 7).

The primary aluminium phase field may be divided into

\* This term is retained for convenience. The constituent is probably a mixture of  $\text{Fe}_2\text{Al}_5$  and  $\text{Fe}_2\text{Al}_7$ , or a solid solution of the latter containing nickel.

three parts by straight lines, A D and A F, running respectively from the aluminium corner A to the invariant point D, and to the ternary eutectic point. In the area A E D the secondary separation is that of the aluminium- $\text{FeAl}_3$  binary complex, the composition of the liquid following the binary valley E D. The isothermals of the secondary surface (Fig. 10) are rectilinear, indicating no appreciable change in the composition of the primary aluminium-rich phase during solidification. When the point D is reached, the peritectic reaction between  $\text{FeAl}_3$  and liquid commences and should proceed, at a constant temperature, until either the whole of the  $\text{FeAl}_3$  or the whole of the liquid is exhausted. Actually, invariance lasts for a short time only. Much of the  $\text{FeAl}_3$  is already surrounded by solid aluminium, and can only take part in the reaction by a process of diffusion. Nickel and iron are only sparingly soluble in solid aluminium; the concentration gradient, which determines the rate of diffusion, must therefore be extremely small, and the reaction can only take place to a negligible extent. The  $\text{FeAl}_3$  that is in contact with liquid reacts with it, but is speedily enveloped in solid  $\alpha$  (Fe-Ni), through which diffusion is also slow. The reaction therefore ceases, and the liquid composition moves along the valley D C, depositing the aluminium- $\alpha$  (Fe-Ni) complex until freezing ends or the ternary eutectic point is reached. The solidus surface in the region A E D would be expected to consist of four portions: (1) A narrow field, sloping steeply from the binary eutectic horizontal A D to the line of first appearance of  $\alpha$  (Fe-Ni); (2) a horizontal field at  $649^\circ\text{C}$ , over which freezing ends with the exhaustion of the liquid during the peritectic reaction; (3) a small field, sloping steeply from the edge of the  $649^\circ\text{C}$ . horizontal plane to the line of first appearance of  $\text{NiAl}_3$ ; and (4) the ternary eutectic horizontal at  $638^\circ\text{C}$ . The width of the first field is governed by the solid solubility of nickel in aluminium and  $\text{FeAl}_3$  under the condition employed, and was found to be extremely small, since the addition of as little as 0.05% nickel gave rise to crystals of  $\alpha$  (Fe-Ni) in the micro-sections which could easily be distinguished from the  $\text{FeAl}_3$  crystals. The width of the second field and the temperatures of the third could not be determined experimentally. The line of first appearance of  $\text{NiAl}_3$ , which is the boundary of the ternary eutectic horizontal plane, could not be determined accurately, owing to the very great difficulty of identifying the first small particles of  $\text{NiAl}_3$  in the  $\alpha$  (Fe-Ni) crystal clusters, but it appears to be almost coincident with A D.

In the region A D C F, the secondary separation is that of the aluminium- $\alpha$  (Fe-Ni) binary complex: the liquid composition moves along D C until the ternary eutectic is reached and here freezing is completed. The secondary surface again falls smoothly (Fig. 7) and the isothermals are again rectangular. In this group of alloys  $\text{NiAl}_3$  is always present, and  $\text{FeAl}_3$  absent.

Adjacent to the aluminium-nickel axis A B is a small area A B F. Here the secondary separation is that of the aluminium- $\text{NiAl}_3$  binary complex, the liquid composition following the short binary valley running from the binary to the ternary eutectic. The secondary surface here is nearly horizontal, since the difference between the binary and ternary eutectic temperatures is only about  $2^\circ\text{C}$ . The solidus surface in the region A B C D consists of two portions: (1) A sloping field, probably very narrow, commencing at the binary eutectic horizontal A B and terminating at the line of first appearance of  $\alpha$  (Fe-Ni), and (2) the ternary eutectic horizontal plane, covering most of the region A B C D, and terminating at the line A D. The line of first appearance of  $\alpha$  (Fe-Ni), which forms the boundary between the two fields, could not be determined accurately owing to the difficulty of identification, but it appears to run parallel to the aluminium-nickel axis and to be distant from it by less than 0.1% of iron.

The primary  $\text{FeAl}_3$  field G E D K H may similarly be divided into two areas: (1) G E D M, in which aluminium is secondary, and (2) D K H M, in which the peritectic

reaction occurs before the aluminium separation temperature is reached. In both areas, the surfaces of separation fall smoothly, and the isothermals (Fig. 7) appear to run parallel to the aluminium-iron axis A G and not to the point representing the composition of  $\text{FeAl}_3$ . The course of the isothermals is thus consistent with Bradley's finding that  $\text{FeAl}_3$ —or  $\lambda$ —is capable of dissolving nickel, though, from the appearance of  $\alpha$  (Fe-Ni) in the microsections, the amount so dissolved under the conditions employed here cannot be large.

In the region G E D M, the separation of aluminium commences before the peritectic reaction temperature is reached, and much of the  $\text{FeAl}_3$  becomes surrounded by solid aluminium and so takes no part in the reaction.

The separation of the binary complex of aluminium and  $\text{FeAl}_3$  commences when the composition of the liquid phase reaches the binary valley E D. From this point onwards the course of solidification is identical with that of the alloys of the region A E D, and needs no further description. The line of first appearance of  $\text{NiAl}_3$  could not be established with certainty, again owing to the difficulty of identification. It lies very close to the line D M and has been assumed to coincide with it.

In the region D K H M the peritectic reaction occurs before the aluminium separation temperature is reached. The primary  $\text{FeAl}_3$  is soon completely enveloped by  $\alpha$  (Fe-Ni). The peritectic reaction soon ceases and the system becomes bivariant again; solidification proceeds, not along the univariant line K D, but across the field K D C, reaching the aluminium- $\alpha$  (Fe-Ni) valley not at D, but at some point below it. The temperature at which the aluminium separation commences is thus not constant, but falls slightly as the nickel content is increased. Solidification ends at the ternary eutectic, and  $\text{NiAl}_3$  is present in all the alloys of this group.

In the remaining region C K D,  $\alpha$  (Fe-Ni) is primary, and aluminium secondary, freezing along D C. Solidification is completed at the ternary eutectic, and  $\text{NiAl}_3$  is present in all the alloys of the group. The course of the isothermals of the secondary surface (Fig. 10) affords definite evidence that the primary constituent  $\alpha$  (Fe-Ni) contains both iron and nickel, and also suggests—since the isothermals appear to be parallel and not convergent—that it may be a phase of variable composition. Thus there is nothing consistent with the view that  $\alpha$  (Fe-Ni) is identical with Bradley's  $\rho$ , though this identity has not been definitely established.

*Constituents Present in the Solid State* (Fig. 8).—The limits of occurrence of the various constituents may be summarised thus:

Aluminium .....	Over the whole range.
$\text{FeAl}_3$ .....	Below the line A D K.
$\alpha$ (Fe-Ni) .....	Over the whole range, with the exception of very narrow strips adjacent to the two axes.
$\text{NiAl}_3$ .....	Above the line A D M.

A two-phase region would be expected, containing aluminium and  $\alpha$  (Fe-Ni) only, separating the aluminium- $\text{FeAl}_3$ - $\alpha$  (Fe-Ni)- $\text{NiAl}_3$  fields, but such a region could not be detected. Over a certain range of compositions, D K H M as many as four phases were present in the solid state. This departure from equilibrium is, of course, due to the premature termination of the peritectic reaction, through the envelopment of the  $\text{FeAl}_3$ . As has been mentioned, the similarity in crystal habit and etching characteristics of the two nickel-bearing constituents led to considerable difficulty in determining their exact limits of occurrence, and to this extent the phase boundaries of Fig. 11 must be regarded as approximate. This is probably not a matter of practical importance: the two constituents are so alike that the phase boundary is unlikely to be associated with any marked change in the chemical or physical properties of the alloys.

Throughout the investigation, no attempt has been made to study equilibrium conditions, and the work has been confined to the examination of slowly cooled alloys, with the object of obtaining some insight into their structure as prepared under ordinary commercial conditions.

# The Positions of the Carbon Atoms in Austenite\*

By N. J. Petch, B.Sc., B.Met.

*By careful photometric work direct X-ray evidence of the location of the carbon atoms in austenite has been obtained. They are found to lie at the centres of the unit cells and at the mid-points of the edges, these positions being the centres of the largest spaces between the iron atoms in the austenite structure. There is never enough carbon in solution for every one of these positions to be filled. The number of carbon atoms per unit cell varies from zero for pure iron to 0.32 for a 1.7% carbon steel, so that, at the most, only one possible position in twelve is occupied. Other theories of the structure of austenite are discussed in the light of these results.*

SINCE austenite is formed by the solution of cementite in  $\gamma$ -iron, it was perhaps natural for the idea to arise that the cementite retains its identity to a certain extent in solution. But when X-ray work supplied a knowledge of the positions of the iron atoms in the various phases of the iron-carbon system the objections to this idea became obvious. In  $\gamma$ -iron<sup>1</sup> the iron atoms form a face-centred cubic structure, whereas in cementite<sup>2</sup> they form a complicated orthorhombic structure. There is no possibility of austenite consisting of a  $\gamma$ -iron structure with the cementite structure fitted into it. Instead, when cementite dissolves in  $\gamma$ -iron there must be an atomic rearrangement such that all the iron atoms, whether derived from the pure iron itself or from cementite, situate themselves on a face-centred cubic lattice. What happens to the carbon atoms is a more difficult problem to solve directly by X-rays because of the low scattering power, but some progress has been made by other methods. Westgren<sup>1</sup> has shown by density considerations that the carbon atoms do not lie on the same lattice as the iron atoms. This follows also from the fact that the addition of carbon increases the size of the unit cell, corresponding to a progressive pushing apart of the iron atoms by the insertion of carbon atoms between them. If the small carbon atoms had replaced iron atoms on the lattice they would cause a decrease in the cell size.

All this evidence is, however, indirect, and the interesting question of the precise arrangement of the carbon atoms in the interstices of the iron lattice is left open. If the forces which hold the structure together tend to keep it as close-packed as possible, it might be expected that the carbon atoms would go where they would cause the least deformation. If, however, the forces between the carbon and iron atoms have directional tendencies, such as are observed in covalent bonding, the carbon atoms may be forced into other positions. A distribution of the carbon atoms, some in one type of interstice and some in another, would be possible only if the two positions had the same free energy, and this is unlikely.

It is of particular interest to see if the positions show any resemblance to those in cementite, in which the carbon atoms are at the centres of triangular prisms of iron atoms.<sup>3</sup> Though this arrangement of iron atoms does not occur in austenite, deformed prisms may be considered to be present, and the carbon atoms might be found at the centres of these.

The object of the present work was to obtain the direct experimental evidence of the location of the carbon atoms which has hitherto been lacking.

## Spatial Considerations

The interstices available have their middle points at the centres of either regular octahedra, regular tetrahedra, or equilateral triangles of iron atoms. These spaces are listed in the order of their size, but in the inverse order of the number present in the unit cell.

Johansson<sup>4</sup> puts forward as evidence that the carbon atoms are in the octahedral positions the fact that if the cell volume is calculated, using the known atomic radii and assuming that there is a carbon atom at the centre of each octahedral interstice, then the result agrees with the value obtained by linear extrapolation of the observed cell volumes to this carbon content. Such evidence is unsatisfactory. If the extrapolation of the observed values is carried out to the carbon content corresponding to either all the octahedral, all the tetrahedral or all the triangular spaces having carbon atoms at their centres, then it is found that the iron-carbon distances are 2.13 Å, 2.05 Å, and 2.44 Å, respectively. The usual distance is 2.03 Å. These austenite values cannot be considered completely reliable, because it is unsafe to assume linear extrapolation over the large range required, for example, from 1.7% to 17.7% of carbon for the octahedral interstices. Allowing for this limitation, the evidence cannot be said to favour any particular one of the three possibilities. It is impossible to avoid these uncertainties due to extrapolation by making calculations at the carbon contents for which the lattice parameters can be measured. At these compositions there are not enough carbon atoms for every interstice to be filled, and the resulting dimensions cannot be calculated theoretically without making arbitrary assumptions.

To sum up, it may be said that by purely spatial considerations it is impossible to obtain any definite evidence of the carbon positions.

## X-ray Intensity Evidence

Theoretically, it should be possible to obtain direct location of the carbon atoms by X-ray methods, but in practice there is the difficulty that the carbon atoms are so light that they have little effect on the intensity of the X-ray reflections. In addition, the accuracy of measurement of intensities is limited by the possibility of errors due to lack of uniformity in the film, irregular development and inaccuracies in photometry, etc. Consequently this method has not previously been used to locate the carbon atoms.

The intensity of an X-ray reflection involves a structure amplitude  $F_{AB}^2$ :

$$F_{AB}^2 = (\Sigma f \cos 2\pi(hx+ky+lz))^2 + (\Sigma f \sin 2\pi(hx+ky+lz))^2,$$

TABLE I  
THE THEORETICAL INFLUENCE OF CARBON ATOMS AT THE CENTRES OF THE VARIOUS INTERSTICES ON  $F^2$  FOR A 1.4% CARBON STEEL

hkl.	Line.	$\gamma$ Fe.	F <sup>2</sup> Values.			Carbon Effect on F <sup>2</sup> (approx. percentage).		
			Interstice—			Interstice—		
			Octahe- dral.	Tetrahe- dral.	Tri- angular.	Octahe- dral.	Tetrahe- dral.	Tri- angular.
111	3	4911	4818	4911	4899	-2	0	0
200	4	4246	4327	4165	4206	+2	-2	-1
220	8	2903	2958	2958	2917	+2	+2	0
311	11	2409	2361	2409	2421	-2	0	0
222	12	2277	2324	2231	2271	+2	-2	0
400	16	1870	1910	1910	1850	+2	+2	-1
331	19	1665	1630	1665	1647	-2	0	-1
420	20	1594	1627	1561	1602	+2	-2	0
422	24	1348	1379	1379	1345	+2	+2	0
{ 511 }	27	{ 1219 }	{ 1193 }	{ 1219 }	{ 1216 }	-2	0	+1
{ 333 }		{ 1219 }	{ 1193 }	{ 1219 }	{ 1246 }			

\* Iron and Steel Institute. February, 1942. (Advance copy).

<sup>1</sup> A. Westgren. *Journal of the Iron and Steel Institute*, 1921, No. I, p. 303.

<sup>2</sup> A. Westgren and G. Phragmén. *Journal of the Iron and Steel Institute*, 1922, No. I, p. 241.

<sup>3</sup> H. Lipson and N. J. Petch. *Journal of the Iron and Steel Institute*, 1940, No. II, p. 95 F.

where  $f$  is the scattering factor of each of the atoms present and  $x, y, z$  are the atomic co-ordinates expressed as proportions of the corresponding cell edges. The summation extends over all the atoms within the unit cell. By this means it is possible to calculate the effect of the carbon atoms in various positions on the intensities of the lines. The results of such calculations for an austenite containing 1·4% of carbon are shown in Table I. The atomic scattering factors used are those given in the International Tables.<sup>5</sup>

It appears that in no case can the carbon atoms produce an effect much greater than the experimental errors in the determination of the intensities. In the triangular interstices the changes would be too small to detect. With the tetrahedral and octahedral interstices the effect is greater, the  $F_{\text{eff}}$  factors being modified by 2%. Further, the tetrahedral positions are distinguished from the octahedral by the fact that some lines are uninfluenced by the carbon atoms and also that lines 4, 12 and 20 are altered in opposite directions in the two cases. For these reflections, therefore, the intensity difference between the two positions is increased to 4%. This is a difference which might be detected by careful photometric work. Thus, while one cannot expect to measure accurately such small changes, it might be possible from a number of determinations to detect the general trend of the changes produced by the carbon atoms, and so to distinguish between the three possible positions.

### Experimental Details

The experimental work required the accurate determination of the intensities of the lines of X-ray powder photographs of austenite. The austenite consisted of a manganese steel made from pure materials in an induction furnace, using a hydrogen atmosphere which was pumped out before the melt was allowed to solidify. The lump was homogenised *in vacuo* for 48 hours at 1,050° C.; the outside layers were removed, and filings were taken, sealed off in evacuated thin-walled silica tubes, annealed at 1,050° C. for 2 hours, and finally water-quenched from this temperature. X-ray photographs taken in a 19-cm. camera,<sup>6</sup> using powder which passed through a 120-mesh sieve, showed only austenite lines. The lump analysed 13% of manganese and 1·43% of carbon.

Before the 13% manganese steel was used, 2% chromium, 1·7% carbon and 2% nickel, 1% chromium, 1·7% carbon steels were tried, but it was found impossible under the conditions of quenching to obtain the powders completely in the austenitic condition, although quenched small lumps can be so retained. Subsequently, at Dr. McCance's suggestion, a 2½% manganese, 1·7% carbon steel was used, but with the same result. The effect may be due to the evacuated silica tube slowing-up the quench, but after quenching from an argon atmosphere in an open boat there was still some martensite. Decarburisation during quenching might account for this latter result. Perhaps, however, it is inherently impossible to obtain complete austenite retention with fine powders of this composition. The small particle size with large free surface could allow the volume change of the martensite reaction to be more easily accommodated, and so the reaction made more possible than in the lump. This indicates a point to be taken into consideration in the application of powder methods to the investigation of states of metastability. The ordinary grain-size effect would not explain the result, since the particle size corresponds to what is considered quite a coarse grain size in steels.

Photographs were taken with Co K<sub>α</sub> and with Mo K<sub>α</sub> radiations, which allowed up to lines 12 and 27, respectively, to be photometered. With molybdenum radiation a monochromator was used to cut out the general radiation, and a thin aluminium sheet was put in front of the film to absorb

the K emission spectrum of iron excited by the molybdenum radiation.<sup>7</sup> By this means a clear background was obtained on the film, but above line 12 only lines 19 and 20 were strong enough to be photometered accurately, so there was little advantage in having the extra number of lines on the molybdenum photograph. Consequently, except for one case, cobalt radiation was used, since the exposures could be taken in shorter times, and there was the further advantage that the depression of the atomic scattering factors of iron and manganese by the absorption-edge effect<sup>8</sup> (*loc. cit.*, p. 315) increased the relative influence of the carbon on the intensities of the lines. Calibration strips were put on the films by the usual rotating stepped-sector method in order to permit correction for the non-linearity in the blackening-intensity curve of the film. Such a correction was only necessary with line 3.

Special attention was paid to the photometry, which was carried out with a Cambridge microphotometer of the Dobson type.<sup>9</sup> Although this is not the most convenient apparatus, it was considered capable of accuracy greater than or equal to that of other forms. In principle it is a null method in which, by a photo-electric cell, the blackening on the film is matched against a standard Ilford wedge of which the blackness increases linearly along its length. Initially the results were unsatisfactory, and success was only obtained with a special wedge manufactured by Ilford's. In this the full 5 cm. available on the instrument were utilised for the density range required. Particular attention had been paid to the uniformity of the wedge in manufacture, but, as an additional safeguard, it was calibrated to allow for slight irregularities in the blackening length curve. Intensity determinations were made on the films at every 0·1 mm. on going through a line. The readings were continued to some distance on either side of the line to determine the average background for the line. After allowance for the film correction, the wedge correction and the background, the area under the curve of intensity against distance on the film was taken as the measure of the intensity of the line.

Six films of austenite were used and, to act as checks, two of pure copper. Except in two cases, each film was photometered twice. With all but the austenite film taken with molybdenum radiation the agreement in intensity between the two separate determinations was within 1%.

### The Observed Intensities

For any line in a powder photograph the intensity is given by :

$$I = F^2 \cdot \frac{1 + \cos^2 2\theta}{\sin^2 \theta \cos \theta} \cdot p \cdot A \cdot e^{-B\left(\frac{\sin \theta}{\lambda}\right)^2}$$

where  $\theta$  is the Bragg angle for the reflection,  $p$  is the number of co-operating planes,  $A$  is the absorption factor,  $B$  is a constant and  $\lambda$  is the wave-length of the radiation used.

The term  $e^{-B\left(\frac{\sin \theta}{\lambda}\right)^2}$  is the temperature factor.

Division of the observed intensities by  $\frac{1 + \cos^2 2\theta}{\sin^2 \theta \cos \theta} \cdot p \cdot A$

gives  $F^2 \cdot e^{-B\left(\frac{\sin \theta}{\lambda}\right)^2}$ . If there were no carbon atoms in the austenite the value of  $F^2$  would in every case be  $16f_{\text{Fe}}^2$ . The value of  $f$  varies with the Bragg angle in a known manner,<sup>5</sup> so that  $16f_{\text{Fe}}^2$  can be calculated for every reflection. This is the value  $F_{\gamma \cdot F_{\text{Fe}}}^2$  in Table I. Division of each

observed  $F^2 e^{-B\left(\frac{\sin \theta}{\lambda}\right)^2}$  by  $F_{\gamma \cdot F_{\text{Fe}}}^2$  would give factors in which

the only variable was  $e^{-B\left(\frac{\sin \theta}{\lambda}\right)^2}$ . Consequently, plotting the logarithm of the result for the various lines against  $\sin^2 \theta$

<sup>5</sup> "Internationale Tabellen zur Bestimmung von Kristallstrukturen," zweiter Band, Berlin, 1935; Gebrüder Borntraeger.  
<sup>6</sup> A. J. Bradley, H. Lipson and N. J. Petch, *Journal of Scientific Instruments*, 1941 (in the press).

<sup>7</sup> A. B. Greninger, *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1935, vol. 117, p. 71.  
<sup>8</sup> A. H. Compton and S. H. Allison, "X-rays in Theory and Experiment," Second Edition, New York, 1935; D. Van Nostrand Co., Inc.  
<sup>9</sup> G. M. B. Dobson, *Proceedings of the Royal Society*, 1923, A., vol. 104, p. 248.

would give a straight line. In the presence of carbon atoms, however, the  $F^2$  values are altered from  $F^2_{\gamma-\text{Fe}}$  by the small amounts shown in Table I. Thus, the observed points should be displaced from the straight line by amounts depending on the correct carbon location.

The procedure was, therefore, to divide the observed intensities by  $\frac{1 + \cos 2\theta}{\sin^2 \theta \cos \theta} \cdot p \cdot A \cdot F^2_{\gamma-\text{Fe}}$  and to plot the logarithm of the result against  $\sin^2 \theta$ . The value of A was obtained by the method of Bradley.<sup>10</sup> The values of  $F^2_{\gamma-\text{Fe}}$  given in Table I were not used, but the slightly different results obtained after allowing for the presence of the 13% of manganese and, in the case of cobalt radiation, for the effect of the absorption edge on the f values of iron and manganese. The magnitude of the absorption-edge effect was calculated by Hönl's method.<sup>8</sup> The observed intensities were in arbitrary units, and were divided by a constant so that in every case the final logarithm values were about unity.

#### Discussion of the Experimental Results

The deviations from the straight-line plot for the various films are collected in Tables II and III, and the average deviations are plotted in Fig. 1. The theoretical changes in  $F^2$  due to placing the carbon atoms in various positions are given in Table I. With cobalt radiation the 2% changes due to the carbon are increased to 2.7%, which for the logarithm values corresponds to a 1.2% deviation from the final straight-line plot.

On account of the experimental errors, great significance cannot be attached to the exact values of the deviations. However, they do seem to establish that for the odd order lines the structure amplitudes are smaller than for the even ones. This is the requirement for carbon atoms in the octahedral interstices, but the deviations shown in Table II are rather larger than the theoretical.

TABLE II  
PERCENTAGE DEVIATIONS FROM A STRAIGHT-LINE PLOT FOR AUSTENITE SHOWING THE INFLUENCE OF CARBON AS OBSERVED FROM X-RAY POWDER PHOTOGRAPHS.

Film No.	Line.						
	3.	4.	8.	11.	12.	19.	20.
2023b . . . . .	-1.5	+1.3	-0.5	-3.2	+2.5	-1.8	+1.8
1792a . . . . .	-1.8	+2.0	+2.6	-1.6	+1.4	—	-1.4
1793a . . . . .	-1.2	+1.0	+3.8	-1.8	+1.1	—	-1.1
1793b . . . . .	-1.8	+1.9	+3.4	-1.9	0.0	—	-1.9
1723a . . . . .	-1.5	+1.2	+3.2	-0.8	+0.6	—	-0.8
1723b . . . . .	-3.5	+3.9	+3.4	-4.2	+1.2	—	-4.2
Average . . . . .	-1.9	+1.9	+2.8	-2.2	+1.1	-1.8	+1.8

In view of the small intensity changes, it is of importance to consider if the observed results can be explained by effects other than the influence of the carbon atoms. It has already been seen that the reproducibility of the measurements by the photometer is as satisfactory as can be expected, and the influence of its inaccuracies and of the irregularities of development, etc., are reduced by taking the average of six films. Irregular inaccuracies in the values taken for the absorption factors and for the atomic scattering factors would affect the result. But, though the calculation of both these factors includes a graphical interpolation, this can be done with enough accuracy to ensure that any irregular variations would not give rise to significant deviations from the straight-line plot. The absolute values of the factors cannot be guaranteed, but any errors in them could not do more than cause the straight-line plot to be slightly curved. The photographs of copper act as a check on this, as well as on the accuracy of the measurements of intensity. Copper gives lines in very nearly the same positions as austenite, and the intensities should, of course, show no deviations from the straight-line plot, except those due to experimental error. The results for copper are recorded in Table III, and it will be observed that the deviations are mainly small, only three out of the ten being at all appreciable. It is possible to fit a slightly

curved line to the copper results, and such a curvature might possibly explain the fact that the deviations for austenite were rather larger than was expected, but the curvature is not large and the points lie on a straight line within the experimental error.

Extinction<sup>8</sup> (*loc. cit.*, p. 415) could not produce irregular variations.

From these considerations it is to be concluded that the observed deviations of the austenite intensities are significant. There still remains, however, the possibility that the deviations are caused by the presence of impurities. Only those impurities which give lines overlapping the austenite lines are of importance. No extra lines are visible on the X-ray photographs, and it is unlikely that an impurity which gives no extra lines detectable by eye could affect the photometer results, unless the pattern of the impurity involved strong lines overlapping the austenite lines and only weak ones elsewhere. The only possible contaminations to any appreciable extent would be iron, martensite and FeO introduced during the preparation of the powders. For these the above condition is not true.

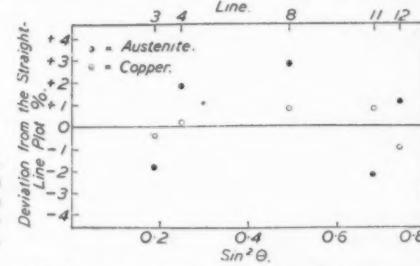


Fig. 1.—The average deviations from the straight-line plot for Austenite and Copper.

a-Iron could not interfere, and martensite would augment line 3, contrary to the observed effect. FeO would produce lines near enough to the austenite lines 3 and 8 to show on the photometric record, but there was no trace of any such lines. The presence of  $\text{Fe}_3\text{O}_4$  is unlikely, because the powders were annealed at 1,050°C. In any case, the strong lines of the  $\text{Fe}_3\text{O}_4$  pattern are not in positions to interfere with the austenite lines. The only lines which could do

TABLE III  
PERCENTAGE DEVIATIONS FROM A STRAIGHT-LINE PLOT FOR COPPER SHOWING THE ORDER OF THE EXPERIMENTAL ERROR.

Film No.	Line.				
	3.	4.	8.	11.	12.
2242a . . . . .	-0.6	+0.4	+1.6	+0.2	-0.3
2242b . . . . .	-0.1	0.0	+0.1	+1.4	-1.8
Average . . . . .	-0.4	+0.2	+0.8	+0.8	-1.0

so are much weaker, and, since the strong lines are not present in sufficient strength to be detected, the weak ones cannot be appreciable. Oxygen could also be present interstitially in solution to a large enough extent to have any effect.<sup>11</sup> The pick-up of inclusions from the crucible is a possibility, but micro-examination showed the alloy to be clean. The pattern of the furnace material is such that the possibility of interference from this source can be dismissed by reasoning similar to that for  $\text{Fe}_3\text{O}_4$ . Even if present, it could not produce the observed trend, because lines 3 and 12 would be augmented. Thus the observed regular changes cannot be explained by impurities.

Another question to be considered is whether ordering of the manganese atoms in special positions could have any effect. It can readily be shown that this could not be so. The lattice points are at 000,  $\frac{1}{2}\frac{1}{2}0$ ,  $\frac{1}{2}0\frac{1}$  and  $0\frac{1}{2}\frac{1}$ . Suppose the distribution of the iron and manganese atoms amongst these positions is so complex that each point has a different scattering factor, say,  $f_a$ ,  $f_b$ ,  $f_c$  and  $f_d$ . Then:

$$F = f_a \cos O + f_b \cos 2\pi \left( \frac{k}{2} + \frac{l}{2} \right) + f_c \cos 2\pi \left( \frac{h}{2} + \frac{l}{2} \right) + f_d \cos 2\pi \left( \frac{h}{2} + \frac{k}{2} \right)$$

<sup>11</sup> M. Hansen, "Der Aufbau der Zweistofflegierungen," p. 703. Berlin, 1936; Julius Springer.

For a face-centred cube  $h, k$  and  $l$  are either all even or all odd. Consequently for every reflection :

$$F = f_a + f_b + f_c + f_d$$

That is to say, that no matter how the metal atoms are distributed amongst the various lattice points, the contribution to each line is the same, and no irregular variations can result.

So far only the possibility of carbon atoms being at the centres of the three spaces has been considered. The valency forces may be such that the carbon atoms are displaced from the centres of the interstices. However, no system based on the displacement from the centres of the tetrahedral or the triangular interstices could produce intensity results at all corresponding to the observed effects. It can also be shown that this is true for any possible system based on the displacement from the centres of the octahedral interstices. On the solution of carbon, austenite remains cubic, and this implies equal deformation along each axis. If this deformation is not produced by the insertion of a single carbon atom at the centre of the interstice, then a complex insertion will be required. A possibility would be the insertion of six atoms into one interstice in the form of an octahedron with the same axes as the iron octahedron. Other possibilities would be eight atoms in cube formation with a carbon atom on the perpendicular through the centre of each face of the iron octahedron, or some still more complicated insertion. Each of these complexes implies considerable displacement of the carbon positions from the centres of the octahedral spaces. Now, the carbon atoms can only exert their maximum influence on the intensities of the lines if they are at the centres of the spaces. This follows, since the intensity depends on the summation of various terms of the type  $\cos 2\pi h x \cdot \cos 2\pi k y \cdot \cos 2\pi l z$ , where  $x, y, z$  are the co-ordinates of the carbon positions. Movement of  $x, y$  or  $z$  from the values corresponding to the centres of the spaces results in these cosine terms becoming less than unity. All the possible complex insertions require such a large displacement from the centres of the spaces that the observed intensity changes could not result. Thus the possibility of insertions other than at the centres of the octahedral spaces is eliminated. A structure with a carbon environment similar to that in cementite is one of these.

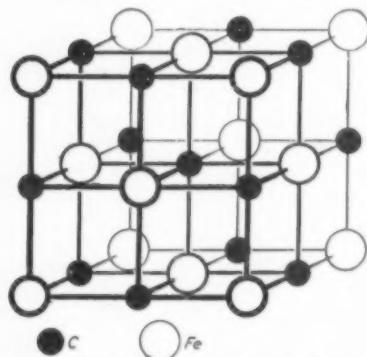


Fig. 2.—The structure of Austenite.

The final conclusion must be that the intensity changes are due to carbon. Although the deviations from the straight-line plot are small, they establish a trend which shows that the carbon atoms are at the centres of the octahedral interstices. Location in the other possible interstices would require the deviations to show quite different trends. The positions of the carbon atoms in austenite are, therefore, at the centres of the unit cells and at the mid-points of the edges. The structure is shown in Fig. 2. The amount of carbon present is not sufficient for each position to be occupied by a carbon atom. At the

most, one position in twelve is occupied. That austenite has this structure is consistent with the fact that in many interstitial structures, such as TaC, CrN, etc.,<sup>12</sup> the small atoms occupy the centres of the octahedral spaces in the face-centred cubic metallic lattice.

#### Other Theories of the Structure of Austenite in Relation to the Present Results

The state of cementite in austenite has been the subject of a large number of discussions from the thermodynamical point of view. Cesàro<sup>13</sup> concluded that the cementite must be present as molecules of carbide. Jeffery,<sup>14</sup> however, considered that there were monatomic molecules of carbon dissolved in monatomic molecules of  $\gamma$ -iron. Yap<sup>15</sup> first agreed with Jeffery, but finally with Cesàro. Körber and Oelsen<sup>16</sup> considered that molecules of carbide were present, and Chipman<sup>17</sup> arrived at the same conclusion for low concentrations. It would seem, however, that, as Austin<sup>18</sup> says, the uncertainties in the data are too great for any conclusion to be drawn by thermodynamical reasoning.

Schwartz<sup>19</sup> believes there are two types of austenite. Solutions in equilibrium with graphite have carbon as solute, those in equilibrium with cementite have the carbide in solution as such. This two-solution theory would require a doubling of the  $A_3$  line in the phase diagram, but no proof of such doubling exists. The crystallographic objections, given in the introduction, to cementite being in solution without dissociation cannot be over-emphasised. Schwartz, in the discussion on a paper by Wells,<sup>20</sup> also quotes unpublished results of Nusbaum to the effect that there is a considerable difference between the lattice parameters of the austenites in equilibrium with graphite and with cementite. The difference is much greater than can be explained by the difference in carbon content, and Schwartz considers that it is to be interpreted as indicating a difference in nature between the two solutions. The lattice parameter quoted for the solution in equilibrium with cementite is in agreement with other determinations, but the solution in equilibrium with graphite gives a value near that of carbonless iron. In the absence of published details it is impossible to comment on whether there could be any experimental explanation of the results, but it is hoped to examine this point during future experiments. Such a difference, if confirmed, would be very important. The lattice parameter of the austenite used in the present work, 3.623 Å., is in agreement with the values obtained for equilibrium with cementite. Also, from electrical-resistance changes during graphitisation Schwartz infers changes in the character of the austenite when the excess cementite is replaced by graphite. The exact interpretation to be put on resistance changes is, however, always a matter of doubt. It is not felt that any convincing evidence of the existence of two austenites has been advanced.

In a theory of the solidification of cast irons Norbury<sup>21</sup> supposes the carbon in cementite and austenite to be present in the diamond form. Crystallographically there is no resemblance at all between the location of carbon in either of these substances and its location in diamond. In the discussion on his paper he limits the significance of his statement to meaning that the carbon atoms are in the same valency state as in diamond, in contrast to the valency state in graphite. However, even when treated from the valency point of view, there is as big a difference between diamond and these substances as between diamond and graphite. In diamond each carbon atom exerts four covalencies pointing towards the corners of a tetrahedron; in cementite and austenite, however, each carbon atom is surrounded by six iron atoms at equal distances. As carbon can exert only four full valencies, it seems likely that these four bonds resonate between the six possible positions.

<sup>12</sup> G. Hägg, *Zeitschrift für physikalische Chemie*, 1931, B., vol. 12, p. 33.

<sup>13</sup> G. Cesàro, *Journal of the Iron and Steel Institute*, 1919, No. I, p. 447.

<sup>14</sup> F. H. Jeffery, *Transactions of the Faraday Society*, 1931, vol. 27, p. 751.

<sup>15</sup> Yap, Chu-Phay, *American Institute of Mining and Metallurgical Engineers, 1931, Technical Publications Nos. 381 and 382.*

<sup>16</sup> P. Körber and W. Oelsen, *Archiv für das Eisenhüttenwesen*, 1931-32, vol. 5, p. 369.

<sup>17</sup> J. Chipman, *Transactions of the American Society for Metals*, 1934, vol. 22, p. 388.

<sup>18</sup> J. B. Austin, *Metals and Alloys*, 1933, vol. 4, p. 49.

<sup>19</sup> H. A. Schwartz, *Journal of the Iron and Steel Institute*, 1938, No. II, p. 205 F.

<sup>20</sup> C. Wells, *Transactions of the American Society for Metals*, 1938, vol. 26, p. 289.

<sup>21</sup> A. L. Norbury, *Journal of the Iron and Steel Institute*, 1939, No. II, p. 161 F.

<sup>22</sup> J. H. Andrew, J. E. Rippon, C. P. Miller and A. Wragg, *Journal of the Iron and Steel Institute*, 1920, No. I, p. 527.

Such a resonating bond is probably to be considered rather similar to a metallic bond.

In a rather early paper, Andrew and his co-workers<sup>22</sup> suggest that there are certain changes in austenite depending on the temperature to which it is heated. These, they conclude, are due to the breaking down on heating of complex molecules of carbide in solution into simpler molecules. They associate this effect with the initial temperature effect on the behaviour of steels. Such a view is not now tenable. It seems probable that their "carbide expansion" is no more than the expansion which occurs when the carbide goes into solution, and the fact that the completion of the change does follow the phase diagram can be explained as due to the sluggish solution or precipitation of the carbides. Sluggish behaviour of the carbides has since been pointed out by Hultgren,<sup>23</sup> Walldow<sup>24</sup> and Carpenter and Robertson.<sup>25</sup> The effect is more marked in the presence of alloying elements, par-

ticularly chromium. The carbide behaviour must be considered in heat-treatment, and, in the interpretation of any variation of properties observed under conditions of continuous heating or cooling, it indicates that care must be taken to realise how far the observations are due to this sluggish carbide effect. But, from the structural point of view, their results do not indicate any changes in austenite on heating.

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<sup>23</sup> A. Hultgren. *Transactions of the American Society of Steel Treating*, 1929, vol. 16, p. 227.

<sup>24</sup> E. Walldow. *Journal of the Iron and Steel Institute*, 1930, No. II, p. 301.

<sup>25</sup> Sir H. Carpenter and J. M. Robertson. *Journal of the Iron and Steel Institute*, 1932, No. I, p. 309.

## The Testing of Welds

By H. N. Pemberton

*A critical and informative survey of the tests applied in industry for the purpose of assessing the strength properties of welded joints is given by Mr. Pemberton in a paper he presented recently to the North-East Coast Institution of Engineers and Shipbuilders. Fatigue, tensile, bend, impact and special crucial tests are discussed in detail, and the significance of these tests, together with factors which may be peculiar to welding and which influence the results obtainable are dealt with. In this article it is only possible to summarise the various tests discussed.*

THE use of welding in the engineering and shipbuilding industries has greatly increased. For some time this increase has been accelerated by the war-time requirements of industry generally. The need for speedy production, and the replacement of iron castings by fabricated mild steel in order to obtain improved resistance to explosive shocks, are two of the main considerations involved. It is therefore important that testing methods should be thoroughly understood in their relation to welding.

In practice, there are many forms and methods of testing, and the procedure adopted is usually governed by the importance and vulnerability of the welded article. The danger is that in adopting a particular system of workshop testing one may be led to believe that the system is sufficiently comprehensive to measure the real efficiency of a welded joint to 100%. For example, based on the results of, say, a static tensile test, the remark may often be heard that "the weld is stronger than the plate." Such a statement, on such evidence, should be accompanied by considerable qualification. Dr. Dorey has said that no practicable system of testing can be devised which alone is sufficient to indicate the strength qualities of the joint.

The riveted joint may in many ways be inferior to the butt-welded joint, but at least engineers know quite a lot about it, from calculation, tests, and experience. The design of riveted joints, based on empirical formulae, is a comparatively simple matter and has given reasonably satisfactory results over a period of many years. Research has shown that the fatigue endurance of well-made riveted joints is higher than the designed stresses normally allowed in such joints. This is not to say, however, that riveted joints do not fail under fatigue in service. Other factors may be involved which are not included in the usual conception of fatigue strength. For example, the simultaneous action of corrosion with fatigue is known to result in a considerable reduction in fatigue endurance of a riveted joint. Again, local hardening of the plate in way of rivet holes is also conducive to fatigue failure under comparatively low stresses.

In this country the application of welding to industry has made steady but laboured progress. Much prejudice has existed, due largely to the engineer's instinctive preference for a mechanical form of joint, and his distrust of a mode of

manufacture which has involved a number of very difficult problems. To-day it can be said that the combined studies of electrical and mechanical engineers, chemists, metallurgists, physicists and radiologists, have been focused on these problems and have brought many of them, if not to a final solution, at any rate to within a range of common understanding.

On the question of welded-joint efficiency, Dr. Hatfield laid it down that "welding, in perfection, is the art of joining parts of the same metal in such a way that the result is a continuity of homogeneous material of the composition and characteristics of the two parts which are being joined together." The author is of the opinion that this definition represents an unattainable ideal and to adopt it as a basis for testing procedure is unnecessary. The primary purpose of any system of routine tests need not be to find how closely the welded joint resembles the solid plate, but should be to ensure that the weld fulfils certain conditions established by experiment, and known to produce a certain standard of strength.

This conception of testing leads away from the question of welded joint efficiency, which, like Dr. Hatfield's definition, remains mainly of academic interest. At the same time it brings into true perspective the whole field of welding research which should be, and largely is, concerned with the problems involved in producing sound, strong and homogeneous welds, rather than the problem of ensuring that the "composition and characteristics" of the parent metal are precisely reproduced in the weld metal.

The question of permissible stresses in welds is one which must soon receive more detailed consideration than has hitherto been the case. The various forms of welded joint are now well established in industrial practice, but the working stress permissible for each form of joint, whether for pressure vessels or structures, is by no means well established, in that there is too much divergence of opinion amongst engineers and manufacturers. A study of available research data would throw considerable light on this question. It is thought, however, that, for any form of joint, due regard should be paid to the fatigue endurance of representative specimens.

### Fatigue Tests

In general, fatigue tests are not suitable to form part of a commercial system of routine testing. Nor are they necessary for this purpose : it is sufficient for the designer and the engineer to have knowledge of fatigue-test data obtained from authoritative sources—data, of course, which relate to particular forms of welded joint, and which have been obtained from tests on specimens of reasonable size. If fatigue endurance were to be accepted as a basis for design, the conditions under which the fatigue specimens have been welded must be accepted as the main guide to welding technique, including type of electrode, electric-current value, and heat-treatment. It is important, therefore, that these relevant particulars should be given by the testing authority side by side with the actual test results obtained.

The author summarised in a table the results of fatigue tests obtained by authoritative investigation in Great Britain and abroad ; only those results were selected as representative of typical welds in mild steel. The number of stress cycles which the specimens withstood without fracture is stated in each case, and it may be accepted that if the range of stress was increased slightly fracture would occur at some lower number of stress cycles.

With regard to good average quality butt-welds, certain general conclusions can be drawn from a study of available fatigue research data, namely :—

1. Heat-treatment has practically no effect on fatigue endurance.
2. Within the usual commercial tensile limits for mild steel plate, the grade of plate has no appreciable effect on fatigue endurance of the weld.
3. The highest class of butt-weld, such as meets the requirements for Class I pressure vessels, possesses double the fatigue endurance—under direct stress—of that obtained in structural welds.
4. Bending fatigue tests are specially sensitive to surface conditions, and, in the words of the Third Report of the Institution of Mechanical Engineers' Welding Research Committee, "There is definite advantage to be obtained by machining the weld metal flush with the plate. Specimens machined all over give higher fatigue values than unmachined specimens. Specimens tested with the weld projecting above the plate fracture at the junction. When the weld metal is machined flush with the plate, the tests show that there is an equal possibility of fracture occurring either in the weld metal or in the plate."
5. For ordinary structural welds, bending fatigue tests give higher results than direct stress tests. The difference is not so marked in the case of the highest class of butt-weld.
6. The main source of danger in fatigue is lack of fusion at the weld junctions. This defect has a more deleterious effect on fatigue endurance than has internal porosity.
7. There is no evidence that an unrefined layer of welded metal in a butt weld decreases fatigue endurance.
8. There is no profound difference in the fatigue endurance of specimens of various thicknesses up to 3 in. thick.

There is ample experimental evidence to justify the foregoing conclusions, and it is suggested that these are of considerable importance to designers and engineers.

Attempts have been made, at various times, to correlate fatigue endurance with the static tensile properties of the material. While the ultimate tensile strength of a material gives no indication of the probable fatigue limit, a study of the subject will certainly show that the elastic and plastic properties play their part in fatigue phenomena. For example, many years ago, Ewing showed that the slip bands produced in a crystal grain under stress may readily form the nucleus of failure if the stressing is cyclical. These slip bands are representative of plasticity within the crystal grain, enabling it to adapt itself to the condition of stress imposed upon it.

### The Static Tensile Test.

This test may be applied to a specimen made entirely of weld metal, or to a specimen cut transversely from the joint, containing a portion of the joint at its mid-length. In the case of Class I pressure vessels, both types of specimens are required to be tested. It is necessary to differentiate very carefully between these two forms of test specimen. Each has decided limitations in the significance of the results obtained. The all-weld tensile test-piece may be cut from a mass of deposited weld metal, as is usually the case when testing the quality of electrodes, or it may be cut longitudinally from an actual butt-welded joint, as in the case of routine tests for pressure vessels. The latter specimen has the merit of being more truly representative of the weld metal contained in the joint. The former is quite a reasonable comparative test for different electrodes, and three standard methods for preparing such specimens are described in British Standard Specification No. 709. This specimen is, of course, machined all over, and is usually of round section conforming to the dimensions of standard test-pieces.

The value of the all-weld tensile test is that it provides a precise indication of the static ultimate strength and ductility of the weld metal. A test-piece cut transversely from the joint, which, for convenience might be called a "transverse tensile specimen," does no more than reveal the breaking strength of the joint under a steadily applied load, and not infrequently reveals very little beyond proving perhaps that the breaking strength of the joint is at any rate not less than that of the parent plate.

A good homogeneous weld has a higher yield-point than mild steel, but is generally not so ductile. Important as is the property of elasticity, good ductility is of special significance in welds, due to the need for the weld metal in a joint to be capable of accommodating itself to high local concentrations of stress which may be induced by the presence of porosity and slag inclusions, even though these defects may be small in themselves. A ductile weld metal will ensure a redistribution of these stresses by local yielding without fracture.

The author recommends a "reduced section" specimen for this test, to ensure that the fracture takes place in the weld, or the weld junctions, if they happen to be a weaker zone. The specimen should not be used in practice for measuring ductility, its chief use being a comparative test of breaking strength, and the broken specimen can also be examined for homogeneity and weld structure.

### The Bend Test.

The "bend test" is a simple and ready means of testing butt-welded specimens. In some form or other it can be applied on site, in the workshop, or in the laboratory. Unless, however, the size of the specimen and the method of bending conform to certain recognised rules, the test may be very misleading, and, in fact, the results of many bend tests are almost entirely devoid of any technical significance.

The recognised forms of bend test are : (a) The former bend test ; and (b) the free bend test.

The "former" bend test is one in which the specimen is bent round a former of specified diameter. The diameter of former, dimensions of specimen, and method of applying the bending force, are important factors which have a decided bearing on the results obtained, and for comparative results these factors should be identical for each test.

The "free bend test" for welded joints was originally devised in America, and specified in the Power Boiler Construction code of the American Society of Mechanical Engineers. The specimen, of width  $1\frac{1}{2}$  times the thickness, is given an initial bend at each end and is then placed like a strut in a compression machine. Pressure is applied gradually until failure occurs in the outer fibres of the specimen.

There are various methods of judging the performance of both "former" bend tests and "free" bend tests, and an exhaustive investigation of the subject was made in 1935 by the late L. W. Schuster, who attempted to correlate the ductility shown by tensile and bend specimens. Mr. Schuster produced curves which, he claimed, gave the full relationship between reduction of area of a tensile test-piece and elongation of the outer fibres of a bend specimen. The curves also show how, for a given percentage elongation of the outer fibres, the severity of the test increases with the width of the specimen.

The performance of the bend test may be assessed by measuring the percentage elongation on the outer fibres of the specimen on a gauge length which is contained in the width of the weld. This assessment of ductility is quite unnecessary when the reduction of area has been measured on an all-weld tensile specimen taken from the weld, and it might be argued that in such cases, as, for example, Class I pressure vessels, the bend test is redundant. In most structural welding work it has not become the practice to prepare all-weld tensile test-pieces from samples of the joint, and in consequence no positive alternative measure of ductility can be made unless the outer fibre elongation is measured on a bend specimen. Schuster has shown that the angle of bend is an uncertain guide to this property.

#### The Notched Bar Impact Test

This test is not generally specified for structural welding work, but it has always been included among the acceptance tests for welded pressure vessels manufactured in Great Britain and in European countries. In the United States of America, with the exception of the Naval Bureau of Engineering, none of the recognised inspecting authorities specifies an impact test. It might appear, therefore, that in Great Britain a somewhat anomalous position exists in regard to Class I pressure vessels, in that a standard of impact strength is laid down for the welded joint, but not for the plate material. The apparent anomaly might be further illustrated by the fact that when an impact test is carried out in a boiler quality plate, the impact value obtained is seldom as high as that obtained in the weld.

Whatever might be the real merits of the impact test, the fact is that in many cases the test is applied without any clear knowledge of the property being tested and with only a vague appreciation of the significance of the result obtained. The author examines the fundamentals of the impact test and then considers whether the variable factors in the test itself vitiate its value. After discussing the subject, he concludes that the impact test is a test for toughness which can be measured, on a comparative basis only, by the energy absorbed in fracturing a specimen in which plastic strain is reduced to a minimum. This is of direct practical value in assessing the ability of a material to resist shock loads which may result in a rapid propagation of a crack. In any structure, this resistance must always depend upon the degree to which plastic strain is inhibited, and for testing purposes the author would prefer to use a form of test such as the Oxford impact test, in which a very high degree of inhibition is obtained.

The fact that a notch itself tends to inhibit plastic strain accounts for the "brittle" type of fracture, such as is obtained in fatigue, and, in fact, in many cases where fracture has resulted from the spreading of an initial crack. The crack itself has, of course, the same inhibiting effect as the notch in an impact specimen. With this in mind, the author is of opinion that in many cases, especially perhaps for structural welding work, a simple "notch bend" specimen would suffice to demonstrate the toughness of the weld. For higher grade welding work, such as for Class I pressure vessels, it seems desirable to retain the impact test usually specified to be carried out on the weld metal and in the fusion zone. In this connection Lloyd's Register Rules for Welded Pressure Vessels specify a minimum Izod value of 30 ft.-lb. on specimens in which the notch is cut in the centre of the weld and in the fusion zone.

#### Crucial Tests

Perhaps a better name for this type of test would be that adopted by the late Professor B. P. Haigh, namely, "constructional tests." Such tests may be described as the testing of typical finished parts by the application of a static load, either tension or compression until the part deforms to a prescribed extent, or until collapse occurs. Examples of crucial tests include the bursting of a cylindrical pressure vessel by internal water pressure, the crushing and twisting of welded assemblies to demonstrate that the weld is not the weakest part under such conditions of loading, and the well-known deformation tests on plates and angles at steelworks, which provide a striking demonstration of ductility if successfully carried out.

Some doubt of the practical value of such tests may be expressed by designers, on account of the apparent irrelevance of the data obtained to the question of design stresses. In the first place, it might be argued, the method of loading may bear no comparison with the method of loading that will be applied in service; secondly, the type of ultimate collapse may have little technical significance, and thirdly, the stresses induced by such tests are probably too complex for accurate mathematical analysis. While these arguments are not true of all forms of crucial test, it is suggested that if the tests are conceived purely as "demonstration" tests, then they serve a useful purpose in begetting an added confidence in the welded part. This aspect is not unimportant where a modern constructional process, such as welding, has to be developed in the face of considerable doubt and prejudice.

Crucial tests on large structural parts have not found much favour in Great Britain, but on the Continent, and especially in Germany, during the past 20 years many of these tests have been carried out and described in technical literature. As examples, welded bridge girders, rolling-stock undercarriage frames, steel building structures, ships' bulkheads, beam-frame connections, engine bedplates, etc., have all been specially fabricated for testing purposes. These tests have been of undoubted use to the designer, if only in revealing unsuspected points of weakness. In Great Britain, on a smaller scale, crucial tests have been carried out by the late Prof. Haigh on straight beams and on right-angle structural joints intended to represent the connection between deck-beams and side frames of a ship. An outstanding feature of Prof. Haigh's tests was that, although the welded joints tested were subjected to loads so severe that stout rolled sections of mild steel were severely bent or buckled, only a few of the very lightest welds showed any visible sign of injury.

In a final section the author surveyed non-destructive methods of testing welded joints. He considers that with progress in the welding industry more and more reliance will have to be placed on non-destructive testing methods. It is reasonable to expect that the cumulative experience of destructive tests, such as have been described, should lead to gradual relaxation of the acceptance test requirements of inspecting authorities, and this desirable end will be the more readily attained if non-destructive methods can be improved, simplified, and brought within the scope of practical workshop application. The author is of the opinion that this subject is of special importance at the present time when speed of production is one of the cardinal factors in the successful prosecution of the war.

Brief reference is made to two practical methods of non-destructive testing of welded joints, namely, X-ray examination and magnetic crack detection. X-ray examination is one of the routine acceptance tests for Class I welded pressure vessels, and is specified by most of the inspecting bodies both in Europe and in the United States of America. In industrial practice X-rays have proved to be the most valuable test applied to the welded joints of pressure vessels, and this method of inspection is almost the complete answer to the old doubt regarding the possibility of internal defects in welds. It is quite true that minute fissures and

hair cracks may escape detection by X-rays, but an already large experience has shown that whatever defects have not been revealed in X-ray examination cannot be of any serious consequence. One is inclined to say that the disadvantage of X-rays is that they reveal too much rather than too little. For this reason there is a need, in the pressure vessel industry, for standard X-ray negatives showing the maximum extent of porosity and penetration defects acceptable for the class of work in question.

The magnetic method is based on the principle that faults in welds increase the magnetic reluctance of the material by reducing the available metal through which the magnetic flux is passing. The testing equipment consists of a means for producing a magnetic flux through the plate at right angles to the welded joint, and a means for detecting the regions of high reluctance.

The means of detection may be broadly classified as :—

- (a) Magnetographs (iron-powder method).
- (b) Instruments measuring magnetic potential drop or flux leakage.

In method (a) iron powder, either dry or suspended in oil, is sprayed over the weld through which a magnetic flux is passing. Cracks, blowholes, poor fusion and other voids in the weld are indicated by massing of the powder directly over these faults. This method can only be relied upon to reveal faults at or near the surface of the weld, and is not suitable for application to fillet-welds, due to the difficulty in arranging a suitable magnetic circuit. Method (b) makes use of "weld test meters" which are instruments for measuring the magnetic potential drop or flux leakage between two points. The ratio of the reading across a weld to the reading obtained from the unwelded plate is a measure of the quality of the weld.

There is reason to think that the magnetic test may be found useful in application to butt welds in pressure vessels,

either as an alternative to X-ray examination or as a preliminary thereto. For pressure vessels other than boiler drums it might be worth while considering whether X-ray examination, a more costly test, could not be restricted to those parts of a welded joint which a magnetic test has indicated to be faulty. Further, for pressure vessels for which X-ray examination is not usually specified, consideration might be given to the relaxation of mechanical test requirements on condition that satisfactory results are obtained by magnetic testing.

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## Aluminium Bronzes

By William Ashcroft

*Aluminium bronzes of suitable composition may be heat-treated to yield a considerable range of mechanical properties, but although at one time favoured because of their high strength, they now attract more attention because of their resistance to corrosive influences and it is this characteristic of these alloys to which particular reference is made in this article. Some applications are also given.*

**A**LTHOUGH the alloy known as aluminium bronze was discovered prior to 1860 and was the subject of many investigations between 1880 and 1900, it is only since the last great war that it has been recognised as an engineering material of construction. Since then its development has been fairly rapid and for many years the casting and working of aluminium bronze has been handled in regular commercial production. Development in its application is due to an appreciation of its properties, which include high tensile strength, excellent resistance to alternating fatigue, and also resistance to corrosion, particularly to attack by sulphuric acid.

Aluminium bronze is essentially an alloy of copper and aluminium, the copper predominating. For many years the most generally accepted proportion in which the two metals were alloyed was in the well-known ratio of 90% copper and 10% aluminium, and this alloy is still used to some extent as a casting alloy when high-tenacity non-ferrous bronze is specified. In modern practice, however, the composition of aluminium bronze of casting quality varies between rather wide limits and, in many cases, additional elements beyond the essential metals, copper and aluminium, bring the bronze within the category of complex

alloys. Certain of these alloys are susceptible to heat-treatment by which their mechanical properties may be improved, or at least modified.

The bulk of the commercial aluminium bronzes contain 5 to 11% aluminium and iron; manganese and nickel are common constituents in the modern alloys. Many compositions are used in practice for both castings and wrought products, but standardisation has to some extent been effected; there are, however, many patented compositions, and there are very few manufacturers who specialise in aluminium bronze who do not have a preferred composition. Users of aluminium-bronze components can probably do no better than be guided by the advice of responsible manufacturers who have had extensive experience with production and applications. The specific composition recommended depends in part on the service properties required, the corrosive medium, heat-treatment (if any), and whether the material is to be cast or wrought.

Alloys of copper and aluminium containing less than about 7.5% aluminium consist of a solid solution, are not heat-treatable, and are not subject to "self-annealing." The composition of the 90-10 copper-aluminium alloy is altered by the addition of other elements to (1) prevent self-

annealing; (2) enhance the mechanical properties; (3) improve the resistance to certain corrosive media; (4) improve the casting or working qualities; and (5) increase the susceptibility to heat-treatment. Solid solution binary copper-aluminium alloys, containing 5 to 8% aluminium, are used for some wrought products, but seldom for castings; these alloys may contain small percentages of iron, manganese or nickel.

As previously mentioned, one of the features of the aluminium bronzes is their high-tensile strength and brief reference to some of their mechanical properties will be of interest. The 90-10 copper-aluminium alloy as sand-cast has a tensile strength of 32 to 35 tons per sq. in., with an elongation of from 20 to 25% in 2 in., and a Brinell hardness of 95. When sand-cast and heat-treated, the tensile strength of this alloy is raised to about 40 tons per sq. in., with an elongation in 2 in. of 8% and a Brinell hardness of 175. Wrought aluminium bronzes are produced with tensile strengths in excess of 45 tons per sq. in., with elongation in 2 in. at about 10%. These alloys have excellent resistance to alternating fatigue and high compressive strength.

Alloys of suitable composition may be heat-treated to yield a considerable range of mechanical properties—for example, very high strength with low elongation or fairly high strength with high elongation, or some combination between the two. Heat-treatment may consist either of quenching from a suitable temperature, or of quenching followed by drawing. The properties obtained depend upon the temperature of quenching and the time and temperature of drawing. For 90-10 copper-aluminium, or some usual modification of this alloy, typical treatment consists in soaking at 900° C., followed by quenching, and then drawing at 400° to 700° C., depending upon the properties desired.

#### Resistance to Corrosion

One of the outstanding characteristics of the aluminium bronzes is their resistance to corrosion by various media. They are highly resistant to attack by many of the ordinary influences met with in industrial operations, including air and polluted atmospheres, sea-water, fresh waters, solutions of sulphuric acid over a rather wide range of concentration, alkaline liquors, certain concentrations of hydrochloric acid, a large number of neutral and acid-salt solutions, many acids and sundry gases. They are, however, attacked by nitric acid, certain chloride and sulphate solutions, some contaminated waters, and some other acids and salts.

The composition of aluminium-bronzes has an influence on their resistances to corrosion, but though one composition may be more resistant than another to attack by a specific corrosive agent, it does not necessarily follow that this composition is better than the second in its resistance to other corrosives. Thus, the binary alloys containing 10 to 12% aluminium and the remainder copper are found to be more resistant to attack by dilute sulphuric acid than more complex compositions; also, the addition of iron to the 90-10 copper-aluminium alloy increases its resistance to attack by dilute sulphuric acid. The presence of iron also improves the corrosion resistance of the binary alloys to some other acids, and the addition of nickel increases the resistance to corrosion by sea-water. Some polynary compositions resist attack by specific media better than binary and ternary alloys. In any case, however, the differences in resistance to corrosion of the various aluminium bronzes are not great, and the usual commercial compositions recommended by manufacturers are highly resistant to attack by many agents that are corrosive to other engineering materials.

These alloys should not be regarded as stainless or non-tarnishable, because, under the action of some corrosive media, greenish-brown films are quickly formed on the surface. In many cases, however, although the alloy is stained, the corrosive attack apparently goes no further and there is no deterioration of the mechanical properties.

Aluminium bronze stands up well in the highly destructive salt-spray test, and it resists corrosive attack by super-heated steam, acid dyes, and many gases arising in industrial work (except gases from nitric acid), including chlorine, oxygen, hydrogen, and sulphuric dioxide. At room temperature aluminium bronze is but slightly affected by hydrochloric acid in concentrations as high as 20%, while with boiling solutions the safe limit is about 5%.

#### Some Applications

In many cases aluminium bronze is used mainly because of its high-tensile or compressive strength, or its excellent resistance to alternating fatigue, and there are many instances where a combination of high mechanical properties and resistance to corrosion call for the use of this alloy, but in other cases the resistance to corrosion is the primary factor leading to the selection of an alloy of this type. Aluminium bronze is available as sand-castings, die-castings, sheet, rods, angles, tubes, wire, forgings, and such details as bolts, nuts, rivets, washers, screws and the like. Many types of castings are produced, and sheet is worked into various shapes by drawing and forming.

Probably one of the most important uses of aluminium bronze is in the construction of equipment for pickling steel parts in sulphuric acid. Tanks, crates, racks and baskets, as well as hooks, slings, wire ropes, chain, and various tank fittings are made of this alloy. Racks are sometimes cast, while crates as usually built of angles and sheet; tanks are constructed of sheets and shapes and may be riveted or welded together. Tie-rods used in the construction of wood tanks for holding sulphuric or hydrochloric acid are often of aluminium bronze, which is also used for the bolts and screws used in such tanks. Equipment for the chemical industry, including pumps, stills, valves, autoclaves, and piping, is made of this alloy. Thus, pumps made entirely of aluminium bronze are used for the handling of sulphuric acid, particularly in pickling operations. Pumps are constructed wholly of aluminium bronze, and comprise castings and forgings assembled with bolts of the same alloy, thus avoiding the severe electrolytic corrosion that occurs when two different metals are in contact when exposed to corrosive influences.

Aluminium bronze is frequently used in ventilation systems under conditions of service that would be very destructive of most other materials, thus, ducts and exhaust fans in many ventilation systems are made of this alloy, particularly those used in pickling rooms, storage-battery rooms, rubber vulcanising plants; newspaper printing works, over linotype melting-pots; drying houses; laboratories; and other places for handling corrosive vapours. In many cases where steel fans are completely destroyed in a relatively short time, aluminium-bronze fans may last indefinitely without special treatment. Owing to its high resistance to corrosion by sea-water, aluminium bronze finds many applications in marine work; it has also long been used for valves, fittings and other components used for handling sulphite liquors used in the paper industry.

The manufacture of aluminium-bronze is not easy, and needs considerable skill and experience; the presence of oxides, especially aluminium oxide, and segregation are the chief difficulties in the production of a good alloy. These troubles are more common in sand-casting this alloy, and as a result, dross, shrinkage, gas cavities and isolated patches rich in aluminium oxide are generally found in defective castings. The strictest attention must be given to details when making the alloy, preparing the mould for the part required, and pouring the metal in order to achieve the desired success. The formation of oxide during pouring can be prevented by protecting the metal with an inert gas, and Hudson\* has discussed an improved technique, using an inert gas, which appears to offer distinct possibilities of obtaining sound castings.

\* Frank Hudson. "The Production of Aluminium Bronze Castings," METALLURGIA, 24, 187.

## Deep-Drawing Tests on Alloy Steel Sheet and Strip

THE extent to which deep-drawing and pressing operations form the principal method of manufacture is not generally appreciated, but they are playing a very important part in modern industry. To facilitate this work considerable attention has been given to the development of materials which possess the quality of ductility to such a degree that they show considerable plastic deformation before exhibiting signs of rupture; much requires to be done, however, before our knowledge of the mechanism of plastic flow can be regarded as other than limited, and experience in deep-drawing is obtained largely by trial and error methods. Thus, the strain applied to materials by plastic deformation through deep-drawing varies with the particular kind employed, and no simple means of measuring the degree of this strain is known. Special experiments are usually necessary to determine which kind of deep-drawing applies a higher strain on the material, and methods of testing so far developed can be regarded as applicable only to the corresponding kind of deep-drawing: the results obtained are not usually transferable to other deep-drawing processes without some modification. This should be kept in mind when considering the usual method of testing the deep-drawing capacity of sheet and strip. These methods are:—

1. *The Erichsen Method.*—In this method the sheet specimen is clamped between die and blank holder with a clearance of 0.05 mm. A rounded-off punch is pressed into it by means of a screw-press, and the depth obtained, at the start of fracture of the specimen, is measured on a scale.

2. *The Hole-enlarging Test.*—In this case the drilled sheet specimen is clamped tightly on the edges and deep-drawn by a special punch, the hole being enlarged more or less according to the properties of the material. The enlargement at the beginning of tearing of the specimen is measured in a percentage of the original diameter of the hole.

3. *The Key- and Deep-drawing Test.*—A wedge-shaped specimen is deformed cold by drawing through a die, and the various parts thus formed, more or less strongly, are tested by the Erichsen method. The ratio of the depth drawn in the cold-drawn parts to the original sheet is used as a measure.

4. *The Cup-drawing Method.*—A cylindrical punch, rounded off at the top, is pressed into a round sheet specimen, which is deformed into a cup by pressing it through a drawing-block. The larger the diameter of specimen to pass into the drawing-block before tearing occurs is the better deep-drawing material. The finished cup may be subjected to a second or more draws with a similar punch of smaller diameter, thus making the test similar to drawing methods used in practice.

These four methods have been applied to three chrome-nickel steels, three chrome-manganese steels, four chrome steels and one carbon steel of various compositions by Pomp and Krisch,\* and the results compared with each other and with the actual behaviour of the materials when producing certain finished articles, but the results, made up in comprehensive tables supported by graphs, did not show sufficient conformity to develop clear relations to each other.

A further purpose of this investigation was to determine whether the deep-drawing capacity of these materials and of four silicon steels of various compositions could be improved by heating to temperatures up to 200° C. Only the cup-drawing method was used for these tests, and it was found that two steels gave the best results at a temperature of about 20° C., five had improved deep-drawing quality at 100° and 200° C. respectively, and with five steels the increase of temperature seemed to have no influence on deep-drawing capacity.

\* Anton Pomp and Alfred Krisch, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, vol. XXII, No. 3.

## Correspondence

### Economy in Steel

The Editor, METALLURGIA.

Dear Sir,

It is becoming more and more evident that drastic economy is essential in the use of alloyed steels, and it may not be long before restrictions in their use may be necessary. This, however, need not alarm many users of alloyed materials, especially where these are being employed largely for the purpose of resistance to wear.

This need can be met by the application of the surface hardening process to the mild carbon steels as well as the high-carbon steels. Where core ductility and toughness is essential, in combination with surface resistance to wear, several mild alloy steels may be employed, which by proper heat-treatment and proper surface hardening will give the required service.

Steels that can be heat-treated to between 40 and 65 tons can be safely surface hardened without upsetting the core properties.

Another feature of local hardening that may be invaluable to designers to meet economy requirements is the use of low-carbon mild steels. Parts which can be carburised where required to be hardened may be allowed to cool down slowly in the furnace, and afterwards be locally hardened; so avoiding distortion troubles, such as occur on quenching. Many parts made in this way may be finish machined before the final hardening operation.

Metallurgists have of late called special attention to the advantages of steels known as carbon high manganese or manganese carbon steels, which are capable of good ductile properties under correct heat-treatment and are hardenable to a high degree. Attention is also drawn to the value of plain carbon steels manufactured by a process which ensures a controlled grain size. Tests have revealed high-tensile properties combined with high izod figures. The President of the Institution of Mechanical Engineers recently published some very interesting data on some of these steels under test.

Another interesting economy in steels may be worthy of mention, and is offered in the work of fabrication by welding. Mild steel employed for a fabricated structure can often be used in combination with carbon steel built into the structure at the places where resistance to wear can be obtained by the surface hardening of these areas. A typical example of this is the fabricated gear-wheel, in which the webs and boss are made from mild steel and the rim from which the teeth are cut is made of a carbon steel, so that the flanks of the teeth can be hardened.—Yours faithfully,

SHORTER PROCESS COMPANY, LTD.,  
A. E. SHORTER, M.B.E.,  
Managing Director.

February 17, 1942.  
Sheffield.

### Platinum Metals on War Service

In his review of the Platinum Metals Industry for 1941, recently published by the International Nickel Co., Charles Engelhard states that an outstanding feature was the rapid growth in the industrial use of these metals, especially in the manufacture of war materials. Platinum, for instance, is used extensively as a catalyst in the production of nitric and sulphuric acids, which, in turn, are consumed in large quantities for the manufacture of explosives. Platinum alloys also perform an important function in producing artificial silk and are also vital components of the modern electrical instruments used by our fighting forces. Palladium is also increasing in importance as an alternative to platinum for many industrial chemical processes.

## Reviews of Current Literature

### Modern Metallurgy for Engineers

OPINIONS differ considerably on what constitutes the ideal course of study for engineers, and it is very doubtful indeed whether agreement will ever be reached. Engineering is such a comprehensive expression for a number of almost separate industries, each of which constitute more or less a specialist industry, it is not surprising that differences of opinion exist on the best form of instruction for the student of engineering. In recent years, however, the wide range of metallic materials which have become available to the engineer, and rapid advancement in the whole field of engineering have made a knowledge of metal essential and for this reason there has been growing agreement that metallurgy should be included in an engineering course; to-day there must be very few universities and colleges that do not regard it as an essential subject in the engineering curriculum.

Until about 25 years ago, there was little need for engineers to know much about metallurgy, since untreated carbon steel, hot-rolled or cold-drawn, was used for about 95% of steel structures and machines. The engineer was interested primarily in four properties—tensile strength, yield-point, elongation, and reduction of area—and in having available an ample supply of cheap steel which, in addition to meeting specifications for tensile properties, would machine easily and fabricate readily. It was considered sound engineering practice to build machines and structures that would carry a much higher load than was anticipated; weight was synonymous with quality, and the heavier the structure the better the design. High factors of safety were used; consequently slight variations in quality, such as structural inhomogeneity, surface irregularities, and numerous others, made little or no difference in designing.

This is no longer true. In recent years weight and strength-weight ratio have become very important. Engineers have come to realise that excess weight not only indicates poor design, but is an inexcusable economic loss. The experience of the motor and aeronautical engineer in designing light-weight structures and machines stimulated similar efforts in other fields of engineering. This is shown by recent developments in machine tools, in light-weight railway rolling stock, and even in bridge and building structures. This emphasis on light-weight is directly related to the development of new types of steel and light non-ferrous alloys and to new treatments for these materials.

While the inclusion of metallurgy in the course of training for engineering is now widely recognised, the time available for the study of the subject usually limits the training to what are generally regarded as the basic principles of metallurgy and frequently attention is directed more to the science of the subject than to the art, with the result that the engineering graduate has only a rudimentary knowledge of metals and their alloys. To supplement this knowledge there is a very wide literature on metallurgy, and this book is an admirable example and one of the best recently published that the reviewer has had the pleasure of reading.

The author's main objectives were to give the undergraduate or graduate student in engineering a broad but concise outline of the art and science of metallurgy, with the hope that this outline will afford a sound understanding of the important characteristics of the metals he will use; to summarise the present status of metallurgy for older engineers who, in the years they have been practising their profession, have lost touch with advances in metallurgical thought and who may not be familiar, therefore, with all the recent developments in metal products; and to survey the whole field of ferrous and non-ferrous metallurgy, with especial attention to structure and properties, for the benefit of those in the metal industries who either have not had the advantage of a broad fundamental training or have been

working in such a narrow field that they too have lost touch with developments in metallurgical fields other than their own. These objects have been achieved in a very satisfactory manner, bearing in mind that the survey occupies only 400 pages. It should be borne in mind that the book has been written for engineers, and attention has been directed to the art of metallurgy rather than to its science.

The method adopted in summarising ferrous and non-ferrous metallurgy is admirable, and the information is well presented. Besides proving invaluable to engineers and engineering students, metallurgists will find the survey both interesting and informative, since it provides a simple means of obtaining a grasp of the present position of metallurgy in relation to engineering. The author has the co-operation of authorities in many metallurgical fields and has combined the information into a very valuable book.

By Frank T. Sisco. Published by Sir Isaac Pitman and Sons, Ltd. Price 22s. 6d.

### The Chemical Analysis of Ferrous Alloys and Foundry Materials

THE importance of chemical analysis for metallurgical research needs no emphasis, since, despite great progress in the use of physical methods of analysis, this method is still an essential part of the study of metals and their alloys. As a means of control of industrial processes, it is still the most generally applied and there is no likelihood that the connection between chemistry and metallurgy will become less, however increasingly the scientific study of metal may become based on physics. Research and control practice in metallurgy have led to great progress in industry, especially is this true in the field of ferrous metallurgy, which has expanded considerably to meet the increasing demands of the engineer. These demands are reflected in the need for rapid analytical methods suitable for complex irons and steels, and the publication of this new book on chemical analysis is opportune, since chemists are striving to simplify methods and to save time without sacrifice of the degree of accuracy sought.

Written from the viewpoint of the works' chemist, this book embraces the marked advances in metallurgical analysis necessitated by the introduction of complex ferrous alloys. Their complexity has rendered obsolete many methods of analysis formerly regarded as standard. The variety and narrow limits of specifications have increased the demands on the works' chemist, who will find the critically revised methods given in this book of great value. Industrial analysts will find much that is fresh and many modern methods, from scattered sources, have been developed and included as text-book methods; in addition, processes developed by the author for the determination of aluminium, beryllium, chromium, tin, iron and manganese are included, as well as reconstructions of many recognised methods for other elements.

In all, twenty-eight elements are dealt with, which include those of recent application, such as boron, beryllium, cerium, selenium, tellurium, uranium, and zirconium. Information on the extraction, general and chemical properties, and application of each element precedes the actual methods of analysis, whilst some account is given of the evolution and the theory underlying these methods. Some indication of the modern methods recommended is shown by the cyanide-oxine and perchloric-cupferron methods for aluminium, the combustion method for sulphur, the glyoxime dichromate process for nickel, and the cupferron-oxalate method for beryllium, which are typical examples. In addition, improved methods are given for the analysis of materials, such as fuels, refractories, gases, ferro-alloys, and non-ferrous metals, while the analysis of non-metallic and gaseous inclusions and systematic methods for "bath" samples are also included.

The general treatment is based on the requirements of both analyst and advanced student; the former requires

rapid and reliable methods, specific for the elements concerned, whilst the student's requirements embrace theoretical consideration of the principles involved in the development of these processes. The author has had many years of practice and research in iron and steel works' laboratories, and is at present at the Bragg Laboratory, Sheffield; on this subject he is an authority of a high order, and this book will be regarded as a standard work on chemical analysis in its relation to ferrous alloys.

By E. C. Pigott. Published by Chapman and Hall, Ltd., Henrietta Street, London, W.C. 2. Price, 28s. net.

### Practical Handbook on Oxy-Acetylene Welding

WELDING has made very great progress in recent years, much of which is due to development in the art of applying this process by the men in the shops. To those men in particular this well-illustrated little book of 174 pages

should prove very useful, because it deals in a practical way with the process of the oxy-acetylene welding of ferrous and non-ferrous materials, including fusion welding and bronze welding. The author deals with the welding shop and its equipment, and in a practical way considers many of the welding problems encountered in various branches of industry. The hints and tips given should greatly facilitate the application of this process to the repair of ferrous or non-ferrous components, and perhaps assist to lengthen the service of parts that would otherwise become scrap. Quite a wide range of welding jobs is discussed from a fly-press to the tipping of carbide tools, and the operations are presented in a way that will be readily understood by the practical welder. This book should prove especially useful in the present national emergency, when there is an increasing need for good welders.

Published by Suffolk Iron Foundry (1920), Ltd., Sifbronze Works, Stowmarket; price 5s.

## Lattice Spacing and Thermal Expansion of Copper

THE values given by different investigators for the lattice spacing of copper vary by considerable amounts, and it is well known that the density of copper calculated from lattice-spacing measurements does not agree with that measured directly. The thermal expansion measured by direct method also varies considerably from that given by the high temperature lattice-spacing of some investigators, although, in the case of silver, the expansion of the lattice and that of the massive metal are in good agreement. It appeared of interest, therefore, to measure the lattice-spacings of different samples of copper in order to see to what extent variations could be accounted for by varying amounts of different impurities, and also to obtain new data on the lattice-spacing of copper at high temperatures. Samples of six brands of copper were supplied by the British Non-Ferrous Metals Research Association and the National Physical Laboratory, and the results of the investigation are reported by Dr. W. Hume-Rothery and K. W. Andrews.<sup>†</sup>

DIRECT LATTICE SPACING MEASUREMENTS.

	Lattice Spacings, Å.					
	Temperature, °C.					
	18.	300.	500.	671.	771.	871.
Present work	3.6074	3.6259(5)	3.6398	3.6526	3.6603	3.6683
Esser, Eilender, and Bungardt <sup>8</sup>	3.6074	3.7275	3.6420	3.6555	3.6637	3.6721

LATTICE SPACINGS CALCULATED FROM EXPANSION OF MASSIVE METAL.						
International Critical Tables <sup>7</sup>	3.6074 <sup>a</sup>	3.6257	—	—	—	—
Rosenbohm <sup>13</sup>	3.6074 <sup>b</sup>	3.6252	—	—	—	—
Henning <sup>9</sup>	3.6074 <sup>c</sup>	3.6251	3.6390	—	—	—
Nix and MacNair <sup>13</sup>	3.6074 <sup>d</sup>	3.6254	3.6394	—	—	—
Eucken and Dannöhl <sup>10</sup> (a)	3.6074 <sup>e</sup>	3.6254	3.6408	3.6563	3.6666	—
Eucken and Dannöhl <sup>10</sup> (b)	—	—	3.6402	3.6560	3.6660	—
aring and Davey <sup>11</sup>	—	—	3.6398 <sup>f</sup>	3.6543	3.6629	3.6716
Esser and Eusterbrock <sup>14</sup>	3.6074 <sup>g</sup>	3.6254	3.6393	3.6521	3.6690	3.6882
Richards <sup>15</sup>	3.6074	3.6258	3.6405	3.6545	3.6634	3.6724

<sup>a</sup> Values assumed for calculation.

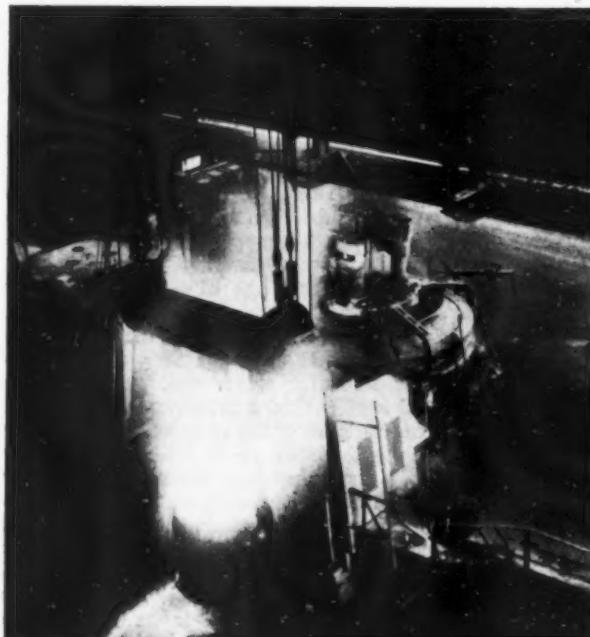
<sup>b</sup> Results from equation of Eucken and Dannöhl.

<sup>c</sup> Results obtained by assuming a linear relation between successive observations.

The analyses of all the samples is given in a table, and the lattice-spacings of all the specimens were measured accurately at room temperature, whilst a sample containing 99.998% copper was investigated at temperatures up to

871°C. The differences were comparatively small, and could be accounted for by the different percentages of the various impurities. The lattice-spacing of pure copper is estimated to be 3.6074 Å at 18°C., and the difference between the observed density and that calculated from the lattice-spacing is very unlikely to be due to impurities in the metal.

The values of the lattice spacings of the 99.998% copper at high temperatures are given in a table, with results obtained by other investigators, which is reproduced. The previous detailed determination of the lattice-spacing of copper at high temperatures appears to be that of Esser, Eilender, and Bungardt, whose results were published graphically, and were clearly not of the highest accuracy since individual points showed considerable deviation from the mean curve. It will be noted in the table that the values found in the present work are considerably lower than those of Esser, Eilender and Bungardt, the differences being of the order of 0.002–0.004 Å.



<sup>†</sup> Jour. Inst. Metals, Feb., 1942, p. 19.

<sup>7</sup> "International Critical Tables," New York, 1927, vol. 2, p. 460.

<sup>8</sup> H. Esser, W. Eilender, and K. Bungardt, Arch. Eisenhüttenwesen, 1938, **12**, 157.

<sup>9</sup> F. Henning, Ann. Physik, 1907, [iv], **22**, 631.

<sup>10</sup> A. Kucken and W. Dannöhl, Z. Elektrochem., 1934, **40**, 814.

<sup>11</sup> W. J. Harling and W. P. Davey, Phys. Rev., 1935, [ii], **47**, 337.

<sup>12</sup> E. Rosenbohm, Physica, 1938, **5**, 385.

<sup>13</sup> F. C. Nix and D. MacNair, Phys. Rev., 1941, [ii], **60**, 597.

<sup>14</sup> H. Esser and H. Eusterbrock, Arch. Eisenhüttenwesen, 1941, **14**, (7), 341.

<sup>15</sup> J. W. Richards, Amer. Soc. Metals, Preprint No. **31**, 1941.

# Latest Vertical Milling Machine

*A new standard model is described which features built-in electrical control gear, direct reading, single control feed change, and direct mounted multi motor drives.*

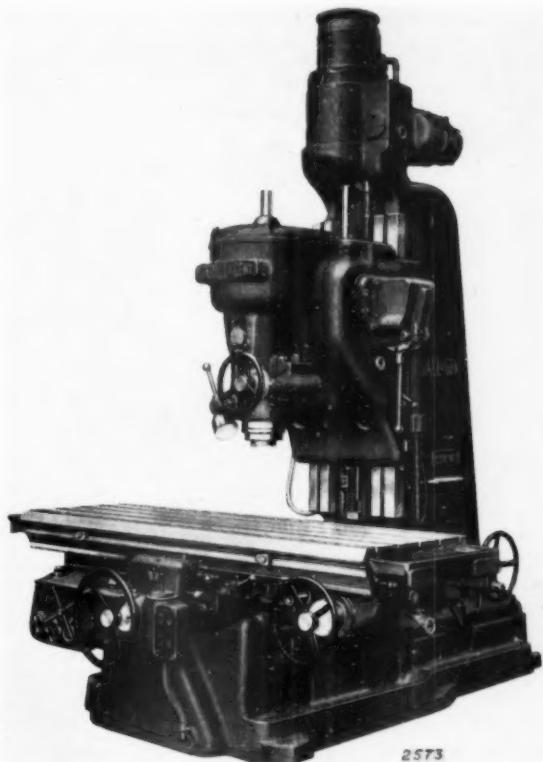
**M**ODERN conditions are making greatly increased demands on milling machines, and developments are being continuously incorporated into design to meet these demands. An instance of this kind is illustrated by two recent models of the CVM 40 vertical milling machine now available, one having the standard milling head with simplified speed selection, and the other with long speed range. Both models are of proved design and similar, with the exception of the head mechanism. Major castings are rugged in design, with sliding surfaces of close texture and resistant to wear. Efficiency of machine is assured by combination ball- and roller-bearing mounted spindle housed in large diameter sleeve, heat-treated nickel-chrome steel sliding gears on splined shafts and direct mounted multi-motor drives. Efficiency of operator is encouraged by simplified speed and feed selection, together with comfortable, handy control.

The standard head model has a speed range of from 9·5 to 238 r.p.m., and is designed to facilitate the selection of the correct cutting speed for a given material. The usual conversion of spindle revolutions to surface speed of cutting is eliminated. Nine spindle speeds are obtained directly from a single control lever. These are not in geometrical progression, but in the progression of cutter diameters from  $1\frac{1}{2}$  in. to 12 in. It is therefore only necessary for the operator to set the speed selector to the diameter of cutter in use.

In the opposite side of the milling head, pick-off gears provide the selected surface speed of cutting. Here, five changes are usually available, 30 ft., 40 ft., 50 ft., 60 ft., and 80 ft. per min. These can be modified to some extent. Correct cutting speeds are therefore easily and quickly obtained by this arrangement without calculation on the part of the operator. Should a faster finishing speed be required, the selector lever is merely moved to the position of the next smaller diameter of cutter, and a readily ascertained percentage increase of surface speed is obtained.

The milling head is accurately fitted to the column ways with full length adjustable strip for wear compensation. horizontally flange-mounted constant-speed reversible motor at the top of the column raises and lowers the head, and is controlled by push buttons. An electric limit switch prevents over-running in the upward direction, and the downward movement can be limited by means of an adjustable dead stop. Contact with this stop operates a slipping clutch, positively avoiding over-run and consequent risk of damage. Simple but very effective lock secures the head in position whilst milling.

The heat-treated high-tensile steel spindle runs in anti-friction bearings which take the radial load. Double-thrust washers take the reaction of the cut and the weight of the spindle. The drive is through six splines in a precision broached driving wheel. The spindle is mounted in a large diameter sleeve which has fine hand adjustment for setting the cut. Back-lash and end play are eliminated by a patented arrangement, and the large diameter micrometer dial permits of easy reading. Efficient clamping is provided for locking the sleeve rigidly in the head when in operation. The sleeve type method of spindle housing gives a short spindle length with minimum distance between spindle drive and cutter, with consequent low spindle torque. Large diameter dial indicator with adjustable depth stop is provided. This eliminates the constant checking of the work on the table and enables the operator to set the cut to within 0·001 of an inch. A series of these stops can be supplied to adapt the machine for a sequence of operation on one component. The indicator can also be used as a dead stop. The spindle nose is flanged for direct mounting



General view of the C.V.M. vertical miller having the standard milling head.

of large diameter face milling cutters, and is bored to standard No. 6 Morse taper with B.S.I. mounting for the large face cutters.

The base of the machine is of substantial construction, in keeping with modern design developments, with the main sliding surfaces and table guides directly under the milling spindle, giving ideal table support under cut. Two well-spread auxiliary sliding surfaces ensure the necessary stability of table. The construction also incorporates chip discharge chutes to either side. The slide ways have a high degree of hardness, the metal being dense and free from porosity, giving maximum wearing qualities. The ways at rear of table are fully protected by close-fitting sliding covers. The base rear extension on which the column is rigidly mounted forms the coolant tank and the drip channels round the base drain into this tank. An impeller coolant pump is submerged in a small auxiliary tank at the rear of the base which prevents fouling and also facilitates cleaning. Faces are provided at the sides and rear of the base, so that levelling can be checked even after installation.

The table is of deep section with tee-slots cut from the solid. Coolant troughs with strainers are provided, and the return to the tank is effected without the use of trailing hose. Longitudinal traverse is through worm and semi-circular rack, substantial ball washers taking the thrust. Worm and rack are cast by a special process which guarantees exceptionally close-grained castings of high-wearing quality. In-traverse is by large diameter steel screw completely protected against falling chips. Here again thrust in each direction is taken by heavy ball washers. Hand adjustment to both longitudinal and in-traverses is controlled by large diameter handwheels with micrometer dials.

# ABMTM

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**GEAR CUTTING MACHINES**

J. Parkinson & Son, Shipley, Yorks.

**GRINDING MACHINES**

The Churchill Machine Tool Co., Ltd., Manchester.

**CAPSTAN and TURRET LATHES**

H. W. Ward & Co., Ltd., Birmingham.

**PLANERS, SHAPERS and SLOTTERS**

The Butler Machine Tool Co., Ltd., Halifax.

**VERTICAL MILLERS, PLANO MILLERS,  
SCREWING MACHINES, BROACHING  
MACHINES**

Kendall & Goss (1920), Ltd., Manchester.

**MILLING MACHINES**

J. Parkinson & Son, Shipley, Yorks.

James Archdale & Co., Ltd.,

Birmingham.



**ASSOCIATED BRITISH MACHINE TOOL MAKERS LIMITED**  
**HEAD OFFICE 17 GROSVENOR GARDENS LONDON S.W.I.**

Each hand motion is duplicated at the rear of the table. Rapid power motion for quick table movement is provided in all directions. Table ways are protected against swarf by adequate covers.

The table feeds are reversible, and obtained from a horizontally endshield mounted constant-speed motor coupled through suitable reduction gearing to the change feed-box. The box is mounted under the left-hand end of the table with clearly lettered direct reading feed-change indicator projecting to the front. The enclosed sliding gears of heat-treated nickel-chrome steel run in an oil-bath and provide eight changes of table feed for each spindle speed. The direction of the table traverse is controlled electrically by a switch which, when placed in any of the four positions, determines the direction of the traverse. The provision of electrical directional selection obviates the possibility of conflicting motions being engaged. The feeds can be tripped at any pre-determined position by means of adjustable stops.

The drive is by vertical endshield mounted constant-speed motor at the top of the column, thence through high-efficiency worm reduction gear, gearbox, and finally to the spindle by another high-efficiency worm and wheel (standard head only). Gears are of heat-treated nickel-chrome steel and slide on splines. Stopping and starting of the spindle-driving motor is controlled by push button conveniently located at the operating position. Stopping of the spindle-driving motor under any circumstances automatically stops the feed motor, obviating possibility of damage by running the work into a stationary cutter. Table-feed motor can be operated at will, with spindle stationary, for setting purposes.

The long speed range model has a speed range of from 15 to 840 r.p.m., the selection being solely by levers. A lever on one side of the head gives high or low range speeds, and a selector on the opposite side the particular speed required for either range. Otherwise, the two machines are similar in construction. They are designed and built by Kendall and Gent (1920), Ltd., Manchester.

### A New General Purpose Lathe

**T**HE last few years have seen many new ideas introduced into lathe design. While the centre lathe remains basically the same in principle, there has been an enormous advance in detail from the cone-driven plain bearing machine to the modern motor-driven all-gearied lathe with anti-friction spindle bearings. In some instances there has been a tendency to over-complicate design—it is really surprising how many gadgets can be fitted on to a lathe—in the belief that everyone who wants a lathe demands it to do everything possible. But the majority of users still want a good sturdy built general-purpose machine, and too many complications are a definite disadvantage. Here the lathe designer is faced by a difficult problem. How far ought he to go? What can he leave out? What functions are vitally necessary to the average lathe user?

Almost every lathe builder has his own particular answer to these questions, and the new Stanley 6½-in. lathe is one of them. This machine, built upon sturdy lines to close limits of accuracy, is likely to provide all those features required by the average user. The whole of the driving equipment is contained within the cabinet leg, through which the fast headstock gives eight spindle speeds in geometrical progression. With a pulley speed of 600 r.p.m., a good general-purpose range of 35–620 r.p.m. is obtained, but by using a two-speed motor, sixteen speeds ranging from 23–825 r.p.m. can be provided.

A multi-disc friction clutch connects the driving pulley to the first driving pinion, giving smooth and easy starting of the machine. The layshafts are mounted on Timken

tapered roller bearings, and the sliding gears on multi-splined shafts. Gear-changing is by parallel sliding gluts on a slider bar; a method giving an easy change. The main spindle of the lathe is made from a carbon steel forging, and is mounted on pre-loaded Timken tapered roller bearings. The interior of the headstock is self-oiling. The makers of this lathe have proved that headstock mountings of this type have definite advantages, being capable of continuous running at high speeds without trouble, sustained accuracy, and freedom from "chatter."

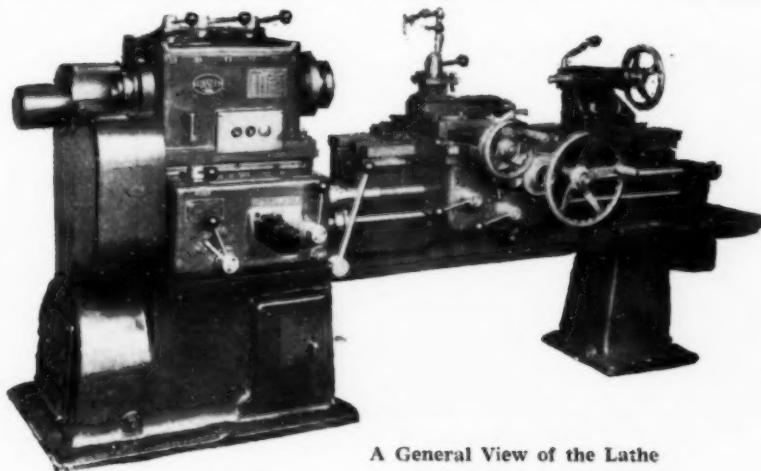
The feed-box is not only sturdy in construction, but is a particularly neat unit. It is capable of cutting standard Whitworth threads from 4–56 t.p.i., without the necessity of altering the change-wheels, provides an adequate range of feeds for all normal work, incorporates a reverse motion to both leadscrew and feedshaft, with a control to disengage the leadscrew when this is not being used. The sliding gears are carried on large diameter multi-spline shafts. The end train is fully guarded by a cast-iron guard; it is, however, easily accessible when it is necessary to change the end-wheels for a special job of work.

The apron is of box construction, with fully interlocking motions. Sliding and surfacing feeds are selected by a knob, and the engagement handle lifts or drops the worm as required by the operator in the workshop. The machine is fitted with a screw-cutting motion which cannot be engaged or disengaged unless the other motions are out of action.

This new design of Stanley lathe has many other useful features: the main operation of the lathe is carried out by a conveniently placed lever at the front of the machine. Easy operation is ensured by the large diameter hand-wheels on the cross-traverse

motion and the apron, while the micrometer dials are large and easily read. Another interesting feature is the travel dial, which can be set to give the travel of the saddle along the bed in inches. The bed is of the narrow guide type, giving adequate bearing surface combined with a high ratio of length/width in guiding the saddle along with it.

Built to Schlesinger limits of accuracy, this lathe, designed and made by the Stanley Machine Tool Co., Ltd., of Halifax, gives all the essentials for versatile work and easy operation, at the same time incorporating the latest ideas in lathe design. The aim has been to produce an accurately and carefully built machine tool for general use, and in this respect the builders can claim to have been successful.



A General View of the Lathe

## Trends in Marine Lubrication

**O**F recent years there has been a considerable advance in our conception of the mechanism of lubrication and in the means adopted in practice to attain it. Such advances have been largely due to the fact that lubricants are nowadays usually products of the petroleum industry, so that research and designing engineers have had at their disposal the encouragement and collaboration of the petroleum technologists. A clearer view of the problems to be solved has thus been mutually obtained, and on the one side has resulted in appreciable alteration to the physical and chemical properties of lubricating oils in general and on the other has permitted much improvement in design and conditions of operation dependent upon lubrication.

The subject of lubrication is a very wide one, and much technical literature has been devoted to it. A more recent consideration of lubrication is given by Dr. Auld and Mr. Lawrie,\* which, although dealing more particularly with marine lubrication, is capable of a much wider application. The authors deal with the modern theories of lubrication : the "fluid" condition and how it is affected by oil stability ; low and high temperature heat/oxidation conditions as affecting turbines and Diesel engines respectively ; the "boundary" condition as it occurs in reciprocating movement and in gears ; the various compromises necessary in choosing single oils with many requirements ; extreme pressure lubricants and the theory of wear ; dependence of modern lubrication on addition agents ; and they give their views on marine lubricating practice and how it may be affected in the future.

The purpose of lubrication is to reduce the production of frictional heat to an extent lower than the rate at which it can be removed. This is accomplished by separating the bearing surfaces by means of a layer of oil which may vary from a continuous flowing film of measurable thickness to a probably discontinuous absorbed layer which in the limit may be monomolecular in dimension. These two conditions are known as "fluid" or "viscous" lubrication, and "boundary" lubrication respectively. In the normal operation of machinery the great bulk of lubrication is of the viscous type, and consequently all matters pertaining to the display of viscosity become important. This applies both to temporary changes due to physical conditions, such as temperature, dilution, emulsification, etc., and permanent changes resulting from chemical instability of the lubricant. In order to follow the trends in the development of lubricating oils, it is necessary that these aspects be given somewhat closer consideration, for on them depends the fact that oils are our chief lubricants.

Although it has not yet been found possible to separate identifiable components from mineral lubricating oils, a great deal of knowledge has been accumulated regarding their chemistry. They are complex hydrocarbons of high molecular weight—mostly within the range of 200–700. From whatever source they are derived they appear to be built up of compounds containing paraffinic or iso-paraffinic nuclei, together with naphthenic and single or multi-aromatic rings. None or few of these compounds contain only one kind of grouping and the behaviour of the oils concerned is governed by the proportion and distribution of the groupings. This composition can only in the broadest sense be correlated with the popular description of oils as being of paraffinic, asphaltic, naphthenic or mixed base : but it may be accepted that paraffinic oils, as typified by Pennsylvanian and mid-Continent oils, contain compounds having a preponderance of straight-chain paraffinic nuclei, while in naphthenic oils, like certain of the Gulf Coast and Russian oils, the paraffin chains, the naphthenic rings and the aromatic rings are more evenly balanced.

The chief adverse conditions which lubricating oils have to meet in practice are heat and oxidation. Behaviour under these conditions more than anything else measures their suitability as lubricants. All choice of crude oil, of refinery operations, of blending and the use of inhibitors is directed towards the end of chemical stability. But although mineral oils are the most stable of liquid lubricants they are still hydrocarbons. If heated sufficiently they will eventually "crack." If exposed to sufficiently severe oxidation conditions they will eventually form acids. Between them, these two facts account directly or indirectly for all the changes which occur to an oil in machine or engine : "directly" by the formation of carbonaceous material or oxygenated bodies, "indirectly" because these products of deterioration, whilst often themselves solids, are still more frequently soluble substances capable of peptising such solids or other solid impurities. This, of course, amplifies subsequent decomposition when the oil is subjected to further heat and oxidation. Moreover, such conditions are those best suited in the presence of intruded water to the formation of difficult emulsions by adsorption at the oil/water interface.

One other severe condition liable to be met with is the intrusion of water. Whether this is present in the form of emulsion—either oil-in-water or water-in-oil—or merely churned around with the oil, the extent of oil surface thereby exposed to the air is vastly increased. Under these conditions, especially with inferior or unsuitable oil, foam may be formed which is only resolved with difficulty. This is an ideal condition for low-temperature oxidation.

There has always been considerable difference of opinion amongst engineers as to the meaning and causes of wear, especially piston-ring and cylinder-liner wear, and the views of the authors on this aspect of lubrication are noteworthy. It is only recently, with advancing knowledge of boundary lubrication conditions, that these difficulties of understanding are beginning to clear. It is necessary first to distinguish between excessive wear and the still wide differences which exist in what may be called "normal" wear. Excessive wear can generally be traced to corresponding abnormal mechanical conditions of design or operation : or to corrosion, abrasion or the nature of the cylinder metal, although these same factors may still be involved in the more normal operation conditions. It has been generally agreed from the work of Ricardo and Williams that in internal-combustion engines, both spark-ignition and Diesel, wear is more a function of chemical activity or corrosion than it is of abrasion. In single-cylinder test engines they found it possible to establish that, particularly below 90° C., condensed carbon dioxide and sulphur dioxide from combustion of the fuel are chiefly responsible for wear. This would appear to relegate the role of the lubricating oil in this respect to the secondary one of protecting the surfaces against condensation or the absorption of acidic radicles. This is not the whole story, however. Wear, in whatever manner it occurs, is still chiefly measured in cylinders towards top dead-centre where boundary conditions are most likely to occur. Moreover, any wear which does occur other than by corrosion cannot obtain if the lubrication is wholly viscous or hydrodynamic in character.

Mechanical wear must be regarded as a natural accompaniment of the boundary condition, for excessively high temperatures to prevail at the points of metallic contact must be followed by welding and tearing leading to ever higher temperatures and more welding unless steps are taken to prevent it. The long chain polar molecules of the oiliness agents alone cannot give adequate protection, since the local high temperatures would quickly destroy the absorbed film, but by redistributing the load over a wider area less severe conditions of temperature will prevail and wear will be reduced. The extreme pressure agents themselves cannot do this, since they are corrosive and must to an extent encourage wear.

\* Lt.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc., and C. Lawrie, North-East Coast Inst. of Eng. and Shipbuilders, 1942. Advance copy.

